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## MAPPING HERBARIUM SPECIMENS: A CASE STUDY USING LOCALITY INFORMATION FROM THE UNIVERSITY OF MICHIGAN HERBARIUM'S MICHIGAN FLORA DATABASE

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### ABSTRACT

Museum specimen locality data can be visualized and analyzed using Geographic Information System (GIS) technology. Explicit and standardized references to geographic locations are required for locality information to be compatible with GIS. This paper describes the procedure used to generate information that enabled mapping of over 52,000 herbarium specimens documented in the University of Michigan Herbarium Michigan Flora database. A benefit of the procedure is the ability to process large amounts of data rapidly. Future users of these data must be cognizant of the methods by which the data were collected, especially so that they are aware of sources of locational error. The method is suitable for generating distributional data for use at a state or regional scale or for preliminary assignment of approximate locations that can be refined further as needed.

**KEYWORDS:** geographic information systems; digital mapping; herbaria; natural history specimens; natural history collections; spatial accuracy

### INTRODUCTION

Geographic Information System (GIS) technology permits the display and analysis of information with a spatial component. A GIS allows one to organize and query data based on geographic and other attributes, visually represent data in a variety of ways, rapidly create and update maps, access and edit databased information associated with a mapped feature, and perform spatial analyses. Explicit and standardized references (textual and/or quantitative) to geographic locations enable the use of GIS with museum specimens [e.g., for herbarium specimens of Ontario (Meades et al. 2007) and Wisconsin (Anonymous 2004; and Glen Barry and Jill Rosenberg, personal communications, 2007)]. More recent collections reference geographic coordinates captured by Global Positioning System technology, which can provide precise and accurate locational information as latitudinal and longitudinal coordinates. However, for historical collections, localities are not written according to any consistently followed convention [for examples pertaining to specimens from Michigan, see Voss (1999, 2005)]. Therefore a major hurdle in the application of GIS technology to museum specimens is translating the descriptive locality information into mappable coordinates. This paper describes the methods used to develop a spatial compo-

nent for a subset of specimens documented in the University of Michigan Herbarium's Michigan Flora database and briefly characterizes the resulting data.

The Michigan Flora database, created by Edward G. Voss, presently Curator Emeritus, University of Michigan Herbarium, beginning in 1956 and continuing through the present, contains information from specimens of Gymnosperms (conifers and relatives) and Angiosperms (flowering plants) from Michigan that Voss examined in the process of writing the *Michigan Flora* (Voss 1972, 1985, 1996). The specimens were collected beginning in the early nineteenth century and are from over 20 herbaria. Until 1991 this information was manually typed on paper slips which were then filed. Since then data have been entered into a computer database program (Foxbase for Macintosh, Foxbase Software Inc., Perrysburg, Ohio) from which paper slips fully compatible in format with the typed ones are printed and inserted in the files. The records in the Michigan Flora database represent what was written by the collector on the labels. They also include annotations by specialists, such as those confirming or altering the taxonomic identification. Missing or incorrect information is often noted, which adds greatly to the quality of locational data as well. For example, for 20% of the records used in the current study, the county (or county unit; seven islands/island groups are distinguished in the data from the mainland portions of the counties) was not explicitly stated on the specimen label, but the presumed county was added as an annotation by Voss. Annotations are placed in brackets and therefore distinguished from the original information, so the integrity of that original data is maintained, as in the following locality taken verbatim from the Michigan Flora database:

Mackinac along the Straites of Mackinac west of Pointe aux Chenes, Sect. 22, T 40N, R 4W.  
[T41N, R5W!]

This investigation was based on the 56,776 computerized Michigan Flora database records available as of April 2002. These records pertain to families included in Part III of the *Michigan Flora* as well as new accessions in all families entered 1991–2002. The county-level distributional data are already available through the *Michigan Flora* (Voss 1972, 1985, 1996) and a more recently updated website (Reznicek et al. 2004). In those maps, the collection of one or more specimens from a county is represented in map form as a dot superimposed on the county (or on part of a county in the case of the seven designated islands/island groups). The work described here was undertaken in order to make finer-scale mapping and analyses more feasible and to create a system in which other benefits of GIS could be leveraged, such as access to the specimen-label data via a map interface.

#### METHODS

The major component of the work was to associate locality descriptions with mappable coordinates. Pre-processing of data included data standardization (for example of county name) and creation of new fields to hold the concatenation of the multiple fields used in the original data to hold locality information [multiple fields were used because the system was set up prior to the advent of

computer databases, and the paper slips used had fixed amounts of space for each field. Furthermore, when a computer database was eventually adopted, the fields also had limitations on the number of characters. Thus, in order to ensure that all the text from the labels be included in the database, text sometimes is placed in multiple fields (E.G. Voss, personal communication.) Following data preparation, the specific methods used depended on the type of information available in the locality. When available a U.S. Public Land Survey (PLS) section coordinate was extracted and standardized. It was then associated with a latitude and longitude for the centroid, the geographical center as calculated using GIS software, of the section, using a reference data set for the state maintained by the Michigan Department of Natural Resources.

For the majority of records, however, coordinates were assigned by associating the specimen record with a geographic feature found in an electronic gazetteer. The electronic gazetteer used was the Geographic Names Information System (GNIS), maintained by the U.S. Geological Survey (U.S. Geological Survey 1981). Each feature in this gazetteer is associated with an x and y coordinate in units of decimal degrees. This coordinate is called the 'primary point.' For some feature types (e.g., streams and valleys) additional coordinates are included as well. The primary point of a linear feature depends on the type of feature. For streams, for example, the primary point is the stream's mouth. For areal features, the primary point is the approximate geographic center, with some exceptions. For example, "the primary point of a populated place is the center of the original place such as the city or town hall, main post office, or town square regardless of changes over time (U.S. Geological Survey 1981)." The subset of GNIS data pertaining to Michigan comprised 32,056 unique features.

The selection of a feature in the electronic gazetteer was accomplished using the database software application 4D (4<sup>th</sup> Dimension, San Jose, CA), customized to permit a combination of automated and manual matching of each specimen locality with place name(s) for the relevant county in the reference gazetteer. Scripts that run from within the application find any matches in the reference database. The scripts rely on a simple system of pattern matching. Each entry in the GNIS for the county listed for a particular specimen is compared with the locality itself, and if any string of text in the locality description exactly matches a given entry in the GNIS, that entry is flagged as a potential match. This automated candidate match selection occurs for the entire set of specimen data and requires no user input. Once that step is completed, the user can review and modify the selection(s) for each record by means of a simple interface. For example, when multiple matches for a particular locality occur, the user can select the most appropriate one with a computer-mouse click. When no match is found, or if none of those found automatically are appropriate, the user can easily retrieve the list of places for the county (or other counties if desired) and select an appropriate match if one exists. This feature is helpful for example when there are different versions or spellings of a place name. Of the 22,000 unique localities (i.e., a unique combination of county and place) included in the specimen data, the system found one or more candidate matches automatically for 15,000.

Whether any matches were found by the automated system or not, each record for which there was no PLS coordinate was briefly reviewed. The review was supported by a GIS (using ArcView 3.2, ESRI, Redlands, California) customized for the purpose, in which gazetteer localities could be displayed with county outlines, rivers, roads, and topographic maps. If, for example, a place name is used more than once within a county, the GIS could be used to quickly find the location with which the specimen is best matched, provided that the specimen label has the location information necessary to distinguish among options. State atlases and other references (Hanes and Hanes 1947, Romig 1972, Voss 1978) were consulted as well. Data were reviewed in order by county; this facilitated applying information about localities gleaned from other specimen records.

When multiple place names were available, georeferencing was to the nearest named place. For example, for the locality "South Manitou Island, South End of Lake Florence" in Leelanau County, 'Florence Lake' was selected as the locality (despite the fact that it did not appear as a candidate match because of the difference in the order of the words 'Florence' and 'Lake' between the GNIS and the specimen record). Name changes, missing names, and spelling variations required investigation. For streams, the automated system related a stream name to its default location, the mouth. This set of coordinates was selected unless the locality specifically referenced the headwaters. Because streams generally cover a large linear distance, alternate feature types were used when these were expected to more accurately reflect the actual location. For example, if a stream and a town along a stream were named (e.g., 'along the banks of the Huron River at South Rockwood'), the town was generally selected.

If specimen collection dates are available in addition to location, spatiotemporal analyses and mapping may be carried out. Therefore year of collection was extracted from the field in the original data which held date information exactly as written on the specimen. Simple tools available in Microsoft Excel (such as pattern-searching and filtering) made it possible to extract century and decade/year of the decade. For records for which century was not explicitly given, a century was assigned based on other dated records of the collector, botanical literature, and on the Harvard University Herbaria's online database of botanical collectors ([http://brimsa.huh.harvard.edu/cms-wb/botanist\\_index.html](http://brimsa.huh.harvard.edu/cms-wb/botanist_index.html)).

Last, in order to make some inferences about sampling effectiveness and distributions of numbers of species, a grid with cells 30 km by 30 km was superimposed on the resulting data. The number of specimens and of species was calculated for each grid cell and divided by the area of the land circumscribed by the grid cell. Locations of major herbaria in Michigan cited in Voss (1985, 1996) as having been sources of specimens examined were also superimposed on the data, using the relevant GNIS coordinates.

## RESULTS AND DISCUSSION

The overall result was that 52,967, 92%, of the 56,776 records were georeferenced to locations more specific than county. Township, range, and section (PLS coordinates) were parsed and georeferenced for 18,530 records (35% of the georeferenced records). Of the remaining records, a mappable feature name was associated with 34,437 records (65%). Mapped locations are shown in Fig. 1. For a technical description of the spatial data written according to the GIS community standard, the Federal Geographic Data Committee's Content Standard for Digital Geospatial Metadata, see Simpson 2006.

More than half of the records were from specimens collected after 1950 and another third from 1900 to 1950. A century, decade, and year was assigned to or standardized for 96% of the records; in the original data a four-digit year was explicitly provided for only 37% of the records. The figure of 96% could undoubtedly be improved further with treatment by botanists familiar with the collectors and the specimens.

Records which were not georeferenced range from those that would be impossible to georeference to better-than-county-level accuracy (or impossible to do so with confidence) to those that could easily be georeferenced with additional time. In the former category are records for which a county but no place description was given. In other cases, a place description was given, but a county was not named (either by the collector or in an annotation by Voss). In other cases, the collector's 'locality' was actually a habitat description and would be impossible to locate, e.g., 'plentiful in moist meadow' and 'in shallow water.'

A few records provided names of places that appeared to be in a county other than that which the collector named. Unless a correction to the named county was given by Voss, coordinates were not assigned to these places. For still other records, multiple places by that name exist within the named county. In the course of this investigation many such records were annotated, e.g., a record for 'Little Lake' in Marquette County includes a note indicating that there are 3 places (all lakes) by that name in 2 different parts of the county, and on the previous day the collector has a record from 12 and 16 miles away from each loca-

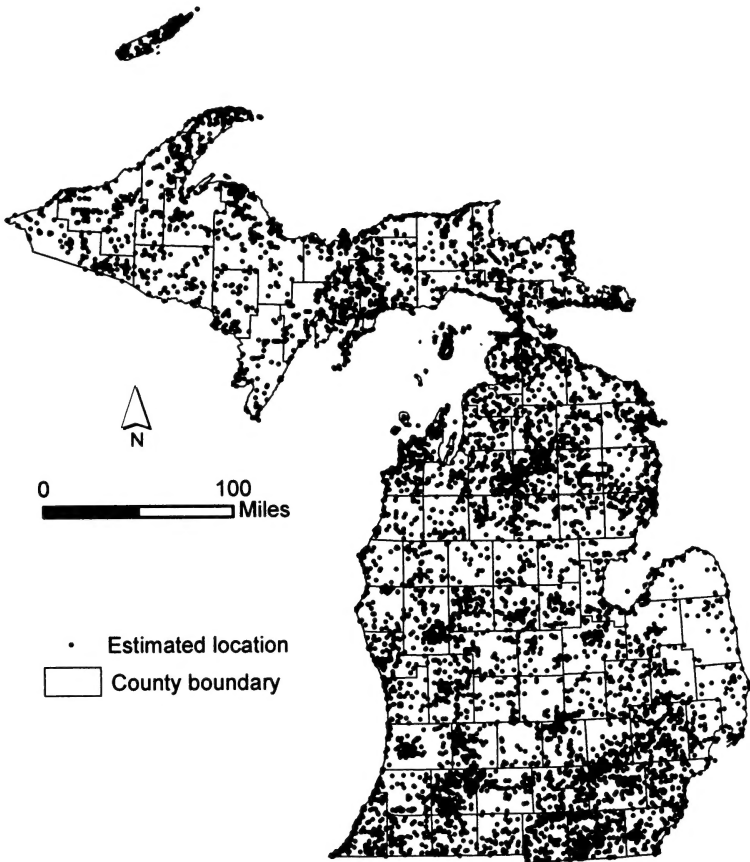


FIGURE 1. Locations associated with all Michigan specimens mapped to better than county-level accuracy.

tion. With a review of the collector's field notes, if available, it might be possible to determine the correct location in cases such as these.

In other cases place names were used which were not found in the various resources used, but with further research they might well be found. For example, the location of 'Peter White Camp, western part of Alger County' for a 1916 record is now easily discoverable through Voss 2005, published after the work described here was concluded. For about a quarter of the unmapped records annotations were added which might assist those interested in adding to the number of georeferenced records.

Some unmapped records contained specific location information for which georeferencing was not supported by the methods described here. For example, many of the unmapped records did not include PLS coordinates or a place name, but did include road intersection/mileage data (e.g., "two miles N. of jct. of Mich.

95 & U.S. 2" in Dickinson County) and thus can be suitably mapped with other methods. Records that provided a county with township and range numbers, but no section number, were not mapped, but certainly could be. Furthermore, township, range, and section information is written in many different ways by collectors, most but not all of which were accounted for in the automated methods used. For example, the township number was not captured for a record for which the township was written as "T.24.N." because the patterns searched for did not include those with periods between the township number and the direction.

Spatial accuracy varies among the georeferenced records greatly, but one indicator of accuracy is the type of geographic entity referenced. For those records associated with a PLS section coordinate, the location will usually be accurate to within 0.72 miles (the sum of the distance from the center of a one-square-mile section to a section corner and the accuracy of the PLS reference data). This error estimate assumes that the PLS coordinate extracted is the true one. A precise error estimate would need to be calculated for each section and specimen individually, for several reasons. First, in cases where more than one section was stated, the first one was referenced arbitrarily, but this may or may not be the best representation of the true location. Second, sections adjacent to state boundaries and shoreline are not necessarily square. Third, while the intent of the Public Land Survey was for a section to be a standard size, in fact there is some variation because of surveying errors and adjustments (Stewart 1935).

For those records for which the mapped location is that of a gazetteer place name, the spatial accuracy varies considerably. Unlike Survey sections, the sizes of towns (for example) are non-standard, and the sizes, boundaries, and centers of towns can change considerably over time. In addition, localities are often described as being a given distance from a geographic feature, and that distance may be an actual distance, a driving distance, or an estimated distance, and may be from the edge of a feature such as a town, the center of town, or some other reference point now impossible to ascertain. Generalizations about the magnitude of inaccuracy, however, may be made by considering the feature types of the place names matched with specimen localities. The top 10 feature types referenced, accounting for 96% of the gazetteer-based records, were, in order of frequency, populated place, civil division, lake, island, park, bay, stream, school, cape, and locale. Over half of gazetteer-based records were matched to a 'populated place (47%)' or a 'civil division (14%).' Of the top 10, or in fact of all, feature types referenced, 'stream (a category that includes both rivers and streams)' is expected to have the potential for yielding the least accurate location, because in some cases a stream or a section of stream in a county extends the distance of a county. Three percent (907) of the specimens were matched to the 'stream' feature type. For over 4,800 records the only available locality information was a township name and county, and for these the feature type was 'civil division.' The accuracy of the assigned location for many of these specimens will be approximately 8.5 miles (distance from the center of a township to a township corner). However, some changes have occurred in township extents, boundaries, and names, so a review of these records is warranted before making conclusions about the accuracy of specific records. The feature type assigned has been retained in the data, so that users can eliminate or work with selected feature types

according to their needs in terms of accuracy or otherwise. A comparatively small source of positional inaccuracy is that of the GNIS itself, which is described as having no more than 10% of the points tested in error by more than 40 feet (U.S. Geological Survey 1981). A greater problem with the GNIS is that it is not a comprehensive database of places in the state. Certainly botanists could add to the list of lakes called 'Deer Lake,' for example. For such common place names, specimen locality has undoubtedly in a few cases been misassigned.

There are a number of ways in which the spatial accuracy, the distance between the mapped location and the best possible assessment of the true location, can be improved with further research. For example, a simple improvement could be made by reviewing the records that reference a township, range, and section to extract more precise locational information, such as quarter-section, when it is available. A review of the data would also reveal cases where the most specific locality information was actually in the habitat field [either because the locality information would not all fit in the locality field or because the information serves both as a habitat description or locality (e.g., 'Evans field' or 'shore of Mud Lake' (examples per communication by E.G. Voss)]. In this particular case of the Michigan Flora data, consulting the specimen itself will in certain cases result in the ability to more accurately place the locality. This is because until recently latitude/longitude and Universal Transverse Mercator coordinates were not entered (E.G. Voss, personal communication). However, because there is no indication in the database of whether such data can be found on the label, retrieving this information would probably be seen as worthwhile only in particular cases. Another example would be to take advantage of the distance and bearing information sometimes provided, e.g., 'six miles northwest of the town of Pinckney.' Currently such a locality is mapped at the GNIS location for Pinckney (populated place). However, a GIS can be used to calculate a new coordinate for the given distance and bearing (or distance and direction along a route) from the GNIS coordinates. A set of such records can be processed as a group when the locational information is appropriately formatted. Furthermore, with on-screen review and editing of individual points in a GIS environment, particularly if done by specialists familiar with the localities, the accuracy can certainly be improved even further. Finally, given the volume of records addressed, there will be oversights and errors, and it is expected that these will be discovered and corrected by users of the data over time. Some errors will be easily discovered, while others more difficult to sort out. Errors that are the result of incorrect or misleading labels will be perhaps most difficult to discover and correct. For example, there are 15 specimens identified as being from Ingham County and north or northeast of the Agricultural College (now Michigan State University). While the county is the correct one for the College, some of these specimens were actually collected over the border in Clinton County (E.G. Voss, personal communication). Similarly, there are over 300 records of collections by C.K. Dodge catalogued as being from St. Clair County and "near Port Huron." These records of course become associated with the coordinates for Port Huron, St. Clair County. However, some of these specimens were collected not only from a different county, but from a different country: they were collected across the river in Canada (E.G. Voss, personal communication). In summary, these

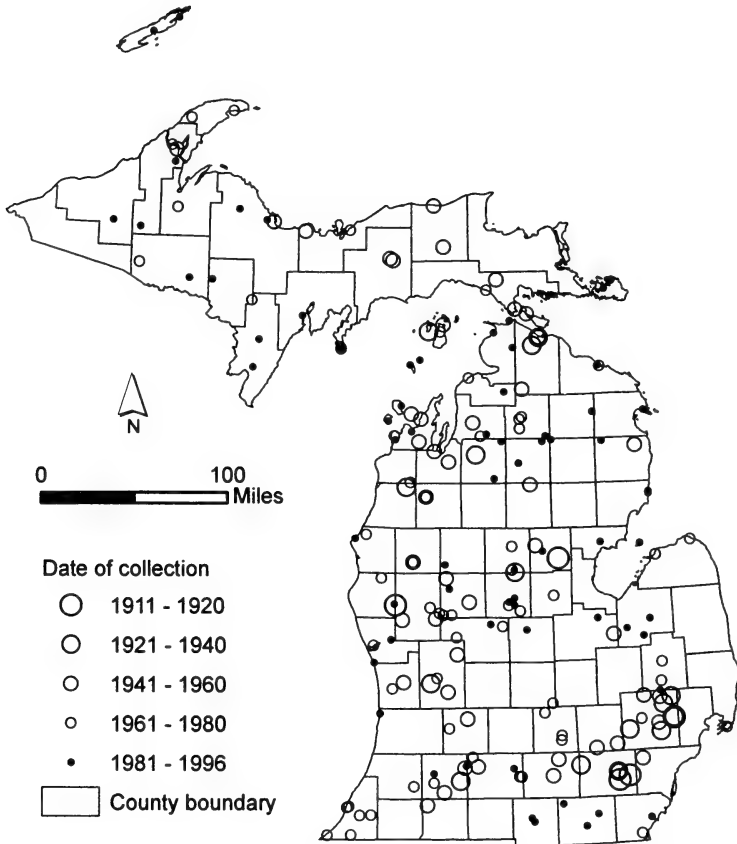


FIGURE 2. Distribution of mapped localities for specimens of *Centaurea stoebe* (= *Centaurea maculosa*, spotted knapweed). Specimens mapped are from (or were at the time the information about them was captured in the Michigan Flora database) the private herbarium of William R. Overlease, the private herbarium of Edward G. Voss, and from herbaria at the following institutions: Albion College, Alma College, Andrews University, Central Michigan University, Cornell University, Cranbrook Institute of Science, Harvard University, Isle Royale National Park, Michigan State University, Missouri Botanical Garden, Morton Arboretum, Northern Michigan University, Seney National Wildlife Refuge, University of Michigan, University of Michigan Biological Station, University of Notre Dame, Wayne State University, and Western Michigan University.

methods assume that the county named was indeed the county in which the collection was made. Review of the data in map form (for example, mapped by species, or mapped by collector and classified by date) by individuals familiar with the expected distributions will facilitate detection of some errors.

Georeferencing rate after the initial automated matching of place names by the database was 170 per hour ( $N=5$  time periods monitored,  $SD=94$ ). By comparison, an entirely manual method used to georeference mammal collections was one tenth as fast, 17 ( $SD=8$ ) records per hour (Stein and Wieczorek 2004).



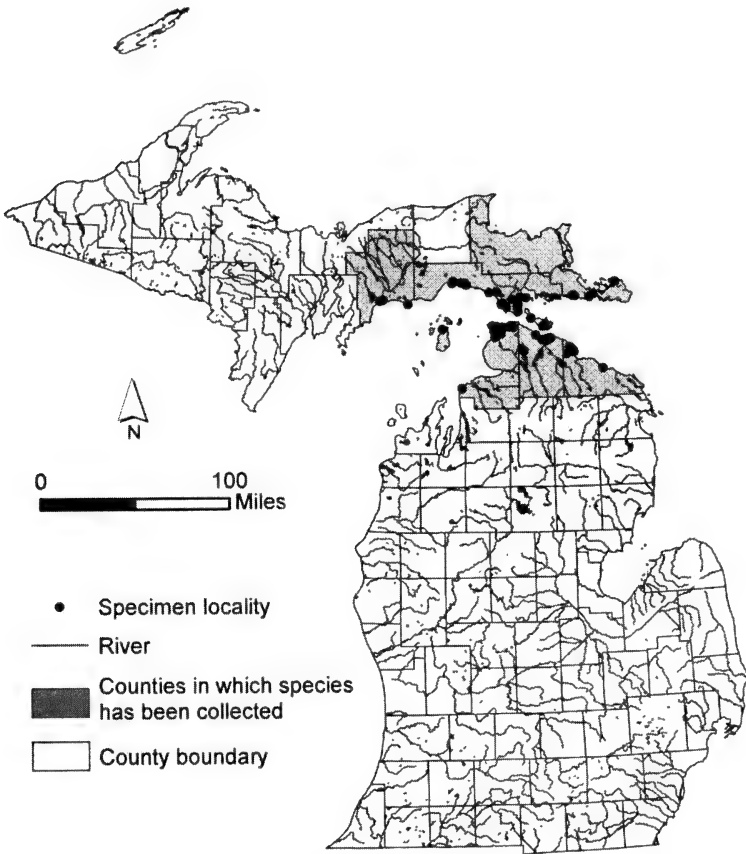


FIGURE 3. Distribution of mapped localities for specimens of *Solidago houghtonii* (Houghton's goldenrod), superimposed on the county-level distribution of specimens. Mapped specimens from western Cheboygan County represent a cultivated individual or individuals (E. G. Voss, pers. comm.). Map excludes Crawford County collections, which may represent a distinct species. Specimens mapped are from (or were at the time the information about them was captured in the Michigan Flora database) herbaria at the following institutions: Butler University, Central Michigan University, Cornell University, Cranbrook Institute of Science, Harvard University, Michigan State University, Ohio State University, University of Michigan, University of Michigan Biological Station, Wayne State University, and Western Michigan University.

One reason for the difference is that the goal of the latter project was to pinpoint the location as accurately as possible and to provide, with full documentation, a measure of the maximum inaccuracy.

An example of a type of simple map that the data now support is shown in Figure 2, where locality data for *Centaurea maculosa* are classified by time period of collection. For an introduced species such as this, depiction of the spatiotemporal pattern of collections can provide insight into the history of invasion. Figure 3 is an example of how in some cases, even at a small scale a map

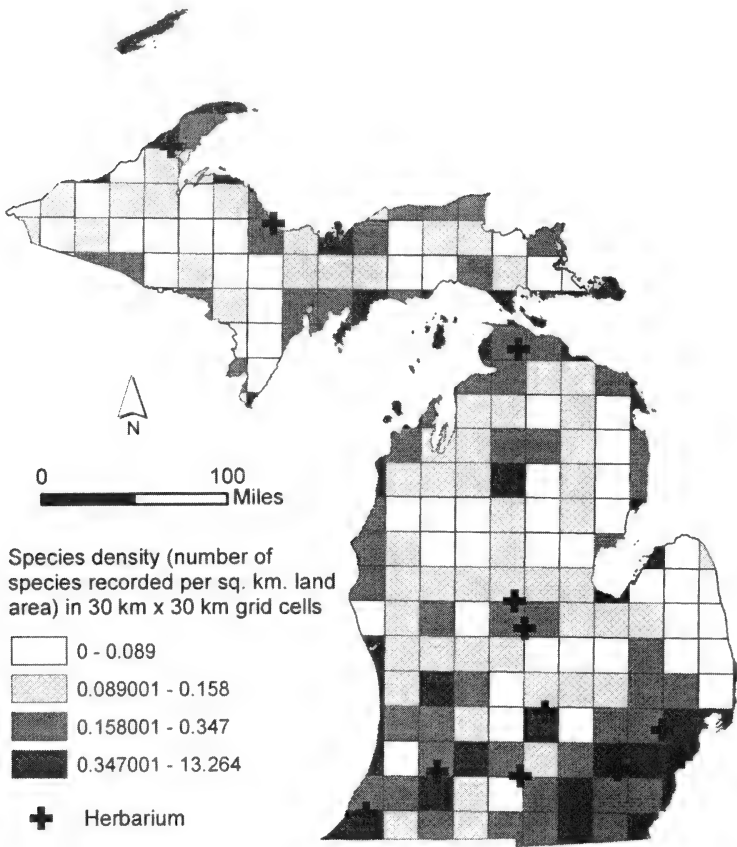


FIGURE 4. Species density in 30 km by 30 km grid cells, as measured by the number of species recorded per square km of land area circumscribed by the grid cell. Superimposed are the locations in Michigan of major collections of the state's flora. Results for specimen density are similar and are therefore not shown.

showing point locations rather than county-level distributions can convey some information about the species's requirements. While not obvious from the county-level distribution for *Solidago houghtonii*, its association with Great Lakes shoreline habitat is apparent from the distribution of localities.

Taken as a whole, the data suggest that knowledge of the species occurring in many areas of Michigan could benefit from further collecting/documentation. Figure 4 suggests visually that certain areas, such as islands and certain coastal areas, have been better sampled by collectors than others. In addition the data suggest that botanical knowledge of areas further from major herbaria might especially benefit from further collecting. This apparent pattern could simply be an artifact of the use of just those Michigan Flora records that were available electronically. However, data for the number of species documented in each county,

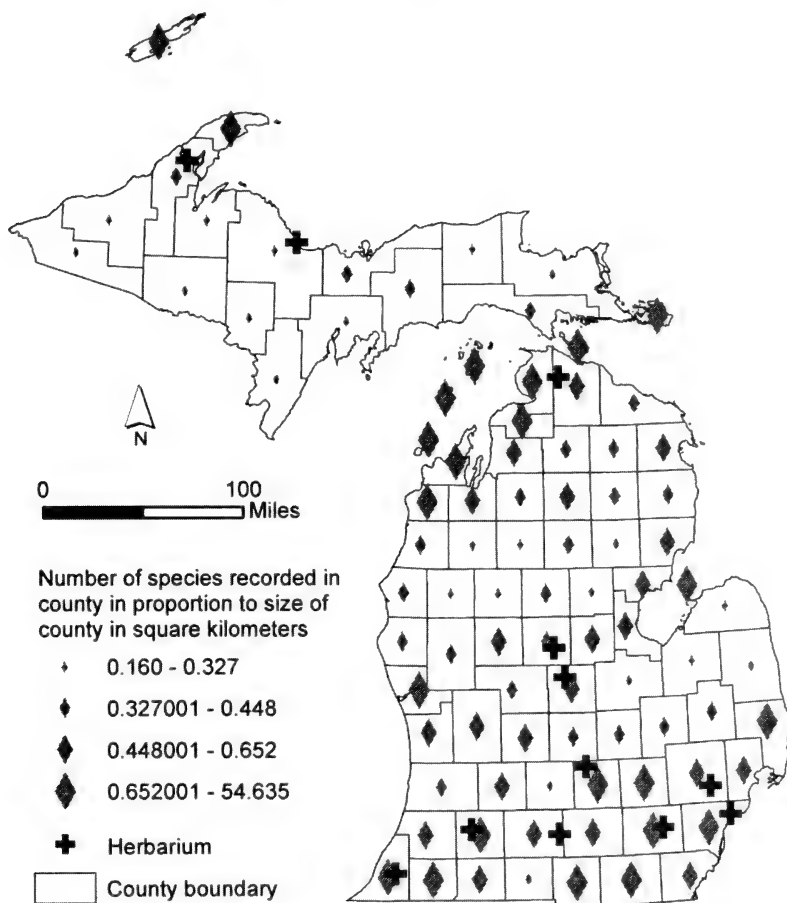


FIGURE 5. Number of species recorded by the complete Michigan Flora database as of March 2004 per county unit in proportion to the size of the unit in square kilometers. Superimposed are the locations of major collections in Michigan of the state's flora. Species richness data are from Reznicek et al. 2004 and are used with permission of the coauthors. County unit designations follow Voss (1972, 1985, 1996).

using the complete Michigan Flora data set as of March 2004, are available, and a pattern of a higher number of species documented in areas near major herbaria (as well as on islands) is suggested visually by these data as well (Fig. 5). Finally, Figure 6 shows the relationship of the number of specimens documented in these 30 km by 30 km cells to the number of species recorded. Many of the cells show few specimen and species records. Based on the species richness and size of better documented counties, areas of this size would be expected to have well over 500 species (e.g., Kalamazoo and Washtenaw counties, with 1604 and 1603 species respectively, have 963 and 771 per 900 sq. km respectively).

One limitation of the mapping method as applied here is that it uses only co-

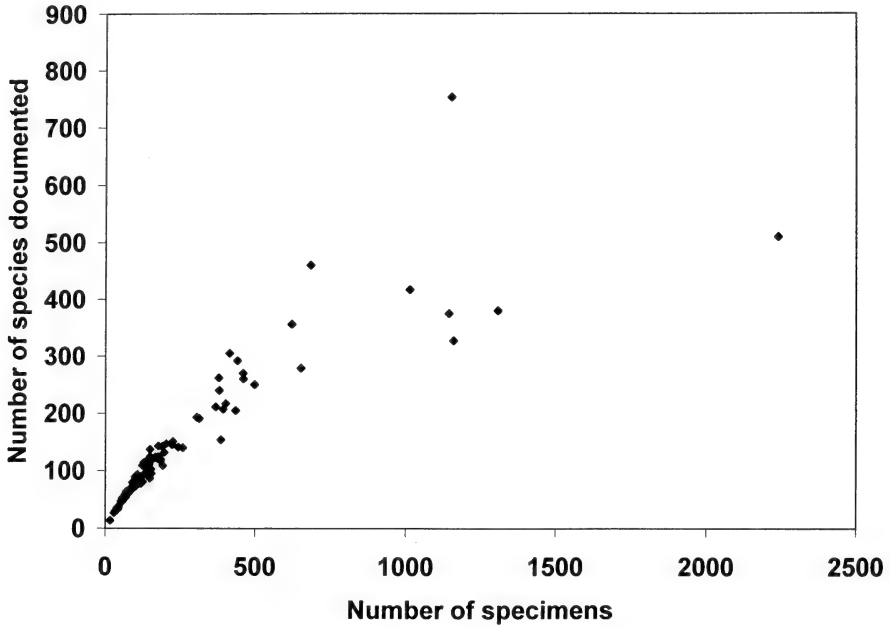


FIGURE 6. Relationship of the number of species documented over 30 km by 30 km grid cells to collection effort as measured by number of specimens collected. Displayed are data for all cells in which the land area circumscribed is within 0.2% of 900 sq. km.

ordinates associated with places named in a federal database. However, one could add known botanical collecting localities to the GNIS data or use another gazetteer. Another limitation is that the GNIS currently supports the representation of places only as points, or at best a series of points. However, a component to the GNIS incorporating the data necessary to display geographic entities as multi-dimensional (e.g., a line feature representing a stream, or a polygon representing a populated place, lake or island) is reportedly in development (Payne and MacIntosh 2004). Such data would facilitate creation of a “footprint” over which a specimen is likely to have been collected. This would be especially valuable for the 15% of gazetteer-based records for which the specimens had no locality information more specific than county and place name. They would also enable automated calculations of accuracy values in multiple directions. Because at a later point it could be desirable to utilize the matched feature name and type, those data, rather than just its x and y coordinates, were retained in the final data set.

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## GERMINATION REQUIREMENTS OF THE EARLY-BLUE VIOLET (*VIOLA ADUNCA*)

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### ABSTRACT

Knowledge of seed germination requirements and other life history characteristics is important for successful management and restoration of native habitat. Little is known of the germination requirements of *Viola adunca* (Violaceae), whose population status is unknown in the mid-west, but declining in the west. We conducted a set of experiments examining the effect of soil type, soil pH, light and temperature on percent germination in *V. adunca*. We found that soil type and temperature regime had especially strong effects on percent germination, while light and pH also affected germination to a lesser degree. *Viola* spp. are declining in at least some habitats in Wisconsin, and *V. adunca* is being used as a restoration plant in the Pacific Northwest, so this research has potential for use in conservation and restoration activities in the Great Lakes region.

**KEYWORDS:** *Viola adunca*, Violaceae germination, restoration

### INTRODUCTION

Biologists consider destruction of native habitat to be the worst threat to biodiversity and natural ecosystems. Along with other human-caused changes, it is believed to be causing a mass extinction of living species (Myers 1986). A recent United Nations report by 1,100 scientists estimates that in the next three decades the earth will lose over 70% of its natural habitats (UNEP 2002).

With such high rates of biodiversity and natural resource loss, conservation and restoration of natural habitats are growing in importance. For many habitats and species, restoration and reintroduction will be the only way in which they may survive. Unfortunately successful restoration projects have been rare (Lockwood and Pimm 1999) and, despite numerous attempts to restore habitat, the ecology of restoration is still not well understood. It is only in recent years that restoration practitioners have begun to use ecological principles to plan and implement their projects (Perrow and Davy 2002).

One application of ecological principles to restoration and conservation is the incorporation of basic life history research in management and restoration plans; for example, an understanding of germination and growth requirements is necessary for successful seeding and transplantation. Little is known about the specific germination requirements for many restoration species (though see Tieu et al. 1999 and Dixon et al. 1995, for studies on smoke enhancement of germination). We investigated the germination requirements for *Viola adunca* J.E. Smith (Violaceae), a widespread perennial plant found in meadows and prairies

throughout western and midwestern North America (Gleason and Cronquist 1991).

Relatively little is known of the status of *V. adunca* populations. It is listed as a species of "special concern" in Massachusetts (<http://www.mass.gov/dfwele/dfw/nhosp/nhrare.htm>) and in Washington state, the Burke Museum reports its conservation status as "not tracked" (<http://biology.burke.washington.edu/herbarium/imagecollection.php?Genus=ViolaandSpecies=adunca>). Populations have been declining in Oregon (Pickering et al. 2000) and Washington (Black and Vaughan 2005). This is disturbing, because *V. adunca* is a restoration plant in the Pacific Northwest as it is the sole host plant for the larval stage of the federally threatened Oregon silverspot butterfly, *Speyeria zerene* ssp. *hippolyta*.

Populations of *Viola* spp. have been declining in wet-mesic and northern upland forest habitats of Wisconsin during the past half century (Bushman 2006; Wiegmann and Waller 2006). Basic and applied ecological research on *Viola* spp. is needed if we are to better understand and conserve this important genus. Research on life history characteristics, including germination requirements of native plants, is essential for successful restoration. Thus an understanding of the germination requirements of *V. adunca* will be useful for managers and restoration ecologists of native prairies, bracken grasslands, and northern upland forests in which *V. adunca* is a major habitat component (WisFlora: <http://www.botany.wisc.edu/wisflora/>).

The conditions required to break seed dormancy can be complex. Factors affecting germination and dormancy may include a specific light:dark regime, temperature regime, and soil properties, among other things. The properties required to break dormancy may even differ between seeds produced in different years by the same species (Baskin and Baskin 1995). Relatively little is known about the germination requirements of *V. adunca*. A number of nurseries carry either the live plants or seed, but a request for germination information resulted in sparse information. Two nurseries suggested that *V. adunca* requires cold stratification. The Oregon Zoo has had some success with leaving seeds outside to overwinter in flats of soil (R. Hanes, pers. comm.). The only paper in the literature that discusses *V. adunca* germination reports zero success for the species under a series of treatments (Drake et al. 1998).

No information could be found detailing indoor propagation of *V. adunca*, as might be useful for restoration ecologists and researchers. Various techniques have been reported for other *Viola* species; for example, a period of dark has been found beneficial in increasing germination success of some *Viola* species (Doohan et al. 1991). Soaking seed with gibberellic acid can also aid in germination of some *Viola* species (H. Ballard, pers. comm.), but getting the concentration and timing right can be difficult (Riley 1987).

We tested germination of *V. adunca* seeds under a variety of soil, light and temperature regimes to see whether germination could be induced ex-situ in a greenhouse setting, in hopes of speeding up the growth and regeneration processes. Specifically, we asked whether soil, light, and temperature affect the germination success of *V. adunca* seeds. We included small pH differences as part of our soil treatment because fire is currently being used in *V. adunca* habi-

tat restoration on the west coast (Pickering et al. 2000) and pH can change following fire. The importance of pH for seed germination is generally species dependent; some species are strongly affected, while others, not at all (Perez-Fernandez et al. 2006).

MATERIALS AND METHODS

Study Species

*Viola adunca* (J.E. Smith) is a temperate, herbaceous, perennial plant growing to 15 cm. The Missouri Botanical Garden lists 15 variants or subspecies; the most widespread is *V. adunca* var. *adunca*, which is found from California to New England (National Plant Data Center: [http://plants.usda.gov/cgi\\_bin/topics.cgi?earl=plant\\_profile.cgi&andsymbol=VIAD](http://plants.usda.gov/cgi_bin/topics.cgi?earl=plant_profile.cgi&andsymbol=VIAD)).

It is known by several common names, including early-blue, dogs-tooth, hook-spur and sand violet. *Viola adunca* is widespread throughout North America, ranging from Greenland to Alaska, and New York to California (Gleason and Cronquist 1991). In the upper midwest, *V. adunca* occurs in moist meadows, prairies, open ground, moist to dry woods, and gravely, sandy soil (Hitchcock and Cronquist 1973; Voss 1985; UWSP Herbarium website: <http://wisplants.uwsp.edu/WisPlants.html>).

Experimental Methods

Some seeds were collected in the field during the growing season of 2004; other seed was obtained from the Oregon Zoo. Seeds were randomized prior to treatment. We conducted two separate germination trials: the first set of seeds was planted on October 29<sup>th</sup>, 2004; the second set between

TABLE 1. Treatments used in the first germination trial. Four treatments were used for soil and four treatments for light/temperature regime, giving a 4X4 factorial experiment with 16 total treatments. "Potting soil" was the sphagnum-based Berger's BM1 brand without fertilizer; "Soil mix" consisted of 40% Pro-Mix Potting Soil, 40% sand, and 20% Fox Farm Planting Mix. All pots were stratified in darkness at 3.9°C for two weeks. *Treatments listed below follow the initial two weeks of stratification.* After the treatment listed, pots were moved to the greenhouse.

TREATMENTS		
Number	Soil	Light/Temperature
1.	Control: potting soil; greenhouse light and temperature regime.	
2.	Potting soil; two weeks in dark at 7.2°C, then greenhouse.	
3.	Potting soil; two weeks at 10 hours light:14 hours dark, 7.2°C, then greenhouse.	
4.	Potting soil; two weeks at 10 hours light:14 hours dark, 7.2°C; two weeks at 12 hours light:12 hours dark, 10.6°C; then greenhouse.	
5.	Potting soil with the pH lowered; greenhouse light and temperature regime.	
6.	Potting soil with the pH lowered; two weeks in dark at 7.2°C, then greenhouse.	
7.	Potting soil with the pH lowered; two weeks at 10 hours light:14 hours dark, 7.2°C, then greenhouse.	
8.	Potting soil with the pH lowered; two weeks at 10 hours light:14 hours dark, 7.2°C; two weeks at 12 hours light:12 hours dark, 10.6°C; then greenhouse.	
9.	Soil mix; greenhouse light and temperature regime.	
10.	Soil mix; two weeks in dark at 7.2°C, then greenhouse.	
11.	Soil mix; two weeks at 10 hours light:14 hours dark, 7.2°C, then greenhouse.	
12.	Soil mix; two weeks at 10 hours light:14 hours dark, 7.2°C; two weeks at 12 hours light:12 hours dark, 10.6°C; then greenhouse.	
13.	Soil mix with the pH lowered; greenhouse light and temperature regime, then greenhouse.	
14.	Soil mix with the pH lowered; two weeks in dark at 7.2°C, then greenhouse.	
15.	Soil mix with the pH lowered; two weeks at 10 hours light:14 hours dark, 7.2°C, then greenhouse.	
16.	Soil mix with the pH lowered; two weeks at 10 hours light:14 hours dark, 7.2°C; two weeks at 12 hours light:12 hours dark, 10.6°C; then greenhouse.	



January 28<sup>th</sup> and February 9<sup>th</sup>, 2005. For the first trial, ten seeds each were sown in 10 cm × 10 cm pots and watered from above with reverse osmosis (RO) water, with eight replicates per treatment (Table 1). After seeds were sown, all flats were placed in a growth chamber for cold stratification at 3.9°C in darkness. After two weeks, flats were separated into light/temperature regimes (Table 1). Soil was kept moist with RO water throughout the treatments. Flats were checked every other day for germination. After initial light/temperature treatments, pots were moved to the greenhouse and randomized throughout the flats. Mean temperatures in the greenhouse varied from 19.6°–27°C during the day, and 14.6°–20.1°C at night. This trial ended on February 2<sup>nd</sup>, 2005. All seedlings in each treatment were erroneously combined before data analysis, so during analysis we counted each treatment as a single replicate.

To determine whether pH affected germination, pH was decreased from 5.5–6.0 to 4.5–5.0 in treatments 5–8 and 13–16 by mixing ferrous sulfate (FeSO<sub>4</sub>) powder directly into moistened soil. The pH of the soil mixture was tested with Hydrión Paper pH strips (Micro Essential Laboratories).

We ran a second germination trial to more clearly test light and temperature requirements for germination. Seeds were sown for the second trial as in Trial 1 with eight replicates per treatment (Table 2); however, control treatments were not subjected to a cold stratification period as they had been in Trial 1. All treatments were planted in COIR-based, Scotts Metro-Mix 336P potting mix. One week into the experiment one of the growth chambers malfunctioned, allowing the temperature to increase to 32.8°C for two days. After discovering the problem, we replanted all treatments except the controls that did not undergo cold stratification (Treatments 1 and 2). We kept the malfunctioned treatments in the growth chambers along with the newly planted treatments, so these two treatments (7 and 8) had 16 replicates rather than eight. Final count of seedlings occurred on April 25<sup>th</sup>, 2005.

Mean daily greenhouse temperature was 23.2°C during the first trial and 24.0°C in the second trial. Night temperature averaged 16.5°C in the first trial, 18.0°C in the second trial. Though not large in magnitude, the temperature differences in the greenhouse during the two germination trials were significant (Two-Sample t-test;  $p < 0.05$ ).

#### Data Analysis

Because replicates in Trial 1 were accidentally combined before data analysis, we analyzed each treatment type (soil, light/temperature) separately using Analysis of Variance (ANOVA) tests; thus

TABLE 2. Treatments used in the second germination trial. Soil type was controlled, with eight variants of temperature and light. The first two treatments started in the greenhouse (no cold stratification). All other treatments were placed in the greenhouse after treatment in the growth chambers.

Treatment Number	Treatment	Light/Temperature Regime
1	Control	Greenhouse
2	Temperature Control	Greenhouse, with two weeks dark
3	Single Temperature Fluctuation with Light	2 weeks @ 12 hours light:12 hours dark; 3.9°C
4	Single Temperature Fluctuation with Dark	2 weeks dark; 3.9°C
5	Multiple Temperature Fluctuations with Light	6 weeks @12 hours light:12 hours dark; 2 weeks each @ 3.9°C, 7.2°C, 3.9°C
6	Multiple Temperature Fluctuations with Dark	6 weeks dark; 2 weeks each @ 3.9°C, 7.2°C, 3.9°C
7	Unplanned Temperature Fluctuation with Light	7 weeks @ 12 hours light: 12 hours dark; 1 week @ 3.9°C, 2 days @ 32.8°C, 2 weeks each @ 3.9°C, 7.2°C, 3.9°C
8	Unplanned Temperature Fluctuation with Dark	7 weeks dark; 1 week @ 3.9°C, 2 days @ 32.8°C, 2 weeks each @ 3.9°C, 7.2°C, 3.9°C

each soil treatment acted as a replicate for the light/temperature test, and vice versa. With the lack of replication we were unable to test for interactions; thus we made the assumption that the two treatments did not interact. Data from the second germination trial failed to meet the parametric test assumptions of normality and equal variance even with transformations, so they were analyzed using the non-parametric Kruskal-Wallis test. All statistical tests were performed in Systat 11.0 (Systat 2004).

## RESULTS

Soil treatments (soil type and pH) in our first germination trial yielded significantly different percentages of germination ( $p < 0.001$ ;  $df = 1$ ; Two-Factor ANOVA) (Fig. 1). There was also a significant interaction between soil type and pH ( $p < 0.001$ ;  $df = 1$ ). Highest percentages of germination were achieved in the unaltered pH, BM1 potting soil. Light/temperature treatments did not differ significantly from one another in the first trial ( $p = 0.95$ ;  $df = 3$ ; Single-Factor ANOVA) (Fig. 2). Mean germination for the entire trial was 15%.

In the second germination trial, overall germination was lower, at 10.75%. Both light and temperature treatments significantly affected germination percentage ( $p < 0.001$ ;  $df = 1, 2$  for light and temperature, respectively; Kruskal-Wallis; Fig. 3). Pairwise comparisons showed that the strong difference in temperature treatments was due to the high germination in Treatment 7, seeds that underwent a dramatic, unscheduled fluctuation in temperature in the growth

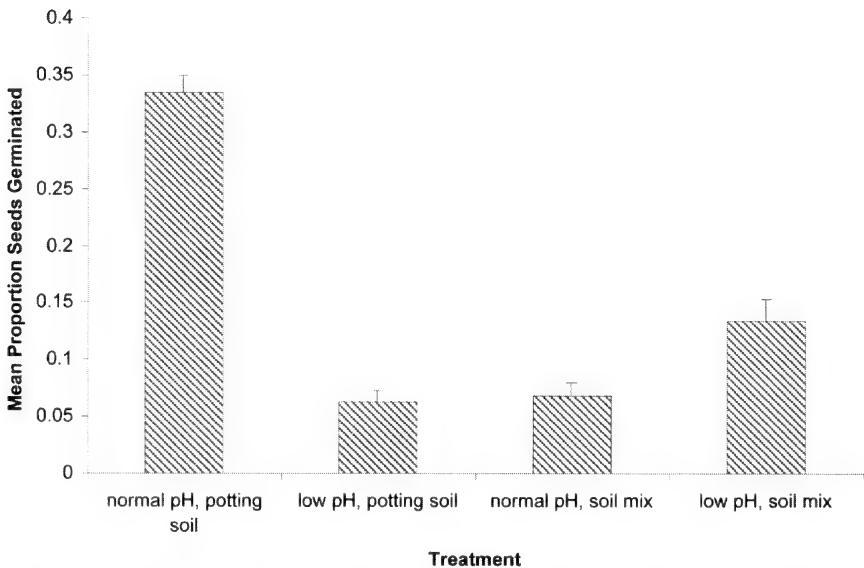


FIGURE 1. The effect of soil type and pH on proportion of seeds germinated in *V. adunca*, Trial 1. Both pH and soil type had a significant impact on germination, and there was a significant interaction effect between the two soil properties. Error bars represent  $\pm 1$  standard error of the mean.

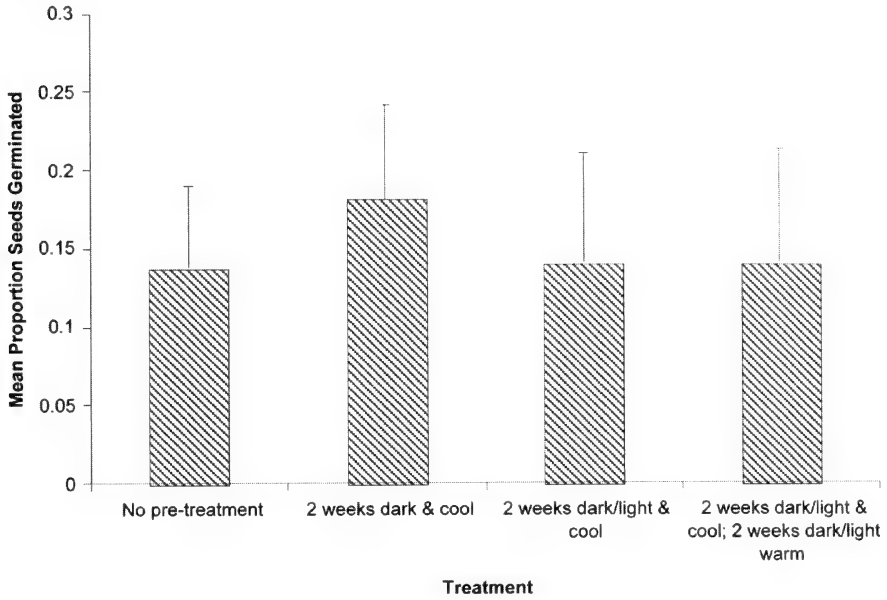


FIGURE 2. The effect of light/temperature treatments on proportion of seeds germinated in *V. adunca*, Trial 1. There were no significant effects of this treatment in Trial 1. Error bars represent  $\pm 1$  standard error of the mean.

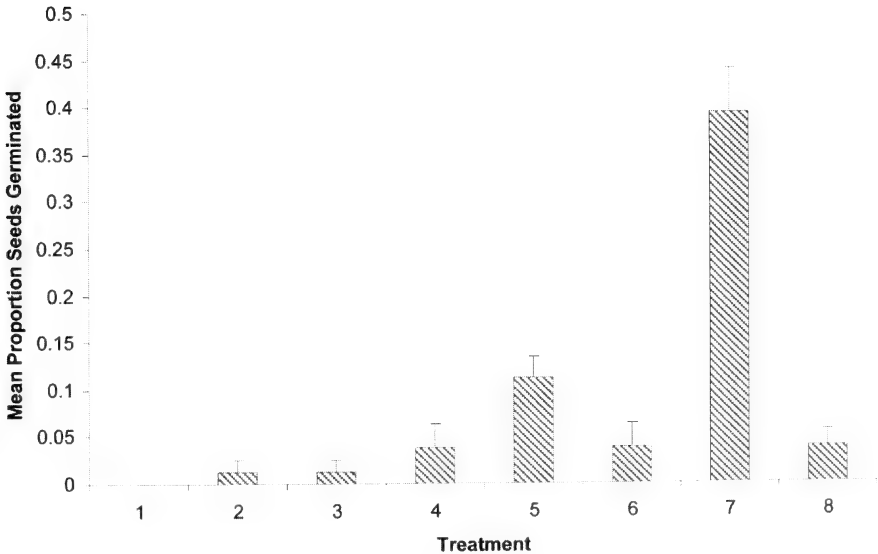


FIGURE 3. Mean proportion of plants germinated per replicate of each treatment in Trial 2. Treatment 7 differed significantly from all others ( $p < 0.001$ ; Kruskal-Wallis). Error bars represent  $\pm 1$  standard error of the mean.

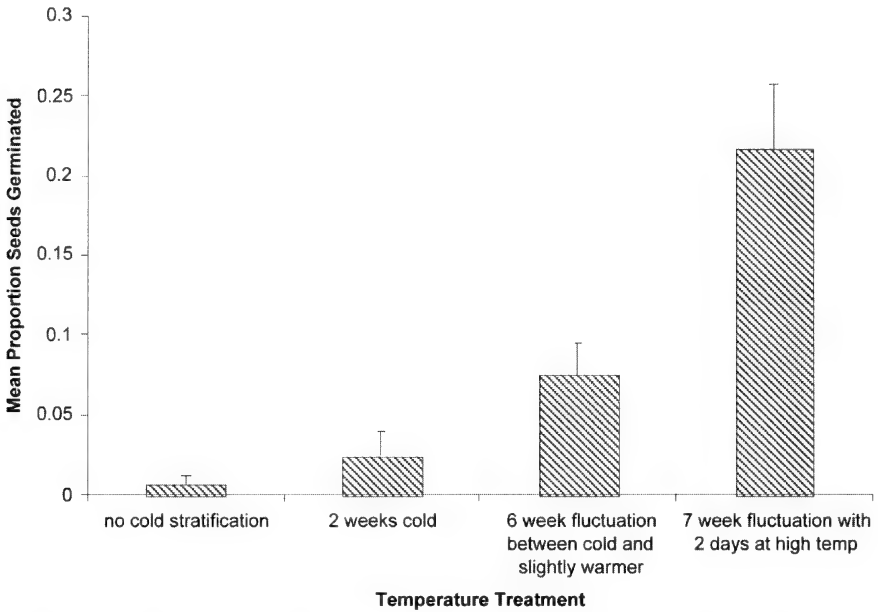


FIGURE 4. The effect of temperature treatments on proportion of plants germinated in Trial 2. The first bar represents replicates with no period of cold stratification (Treatments 1 & 2); the second bar represents replicates with a two-week period of cold stratification (Treatments 3 & 4); the third bar represents replicates with a planned temperature fluctuation of cold, warmer, cold, then greenhouse (Treatments 5 & 6); and the fourth bar represents replicates with the unplanned high temperature fluctuation (Treatments 7 & 8), along with a planned fluctuation as was done in Treatments 5 & 6. Error bars represent  $\pm 1$  standard error of the mean.

chamber (Figure 4). Germination in this treatment differed significantly from all other treatments ( $p < 0.001$ ; Bonferroni Adjustment) while germination in other treatments did not differ from one another. We removed Treatments 7 and 8 from the analysis to see whether the planned fluctuation affected germination. Germination percentage did increase significantly ( $p = 0.004$ ; Kruskal-Wallis) when seeds were subjected to a relatively small temperature increase, then a decrease, in treatments 5 and 6. Seeds that did not have a period of constant darkness exhibited higher germination success ( $p < 0.001$ ; Kruskal-Wallis; Fig. 5); length of the constant dark period did not affect the proportion of seeds that germinated ( $p > 0.05$ ; Bonferroni Adjustment, Pairwise Comparisons).

## DISCUSSION

In spite of the challenges and problems encountered in this project, the two germination trials yielded interesting and potentially useful results. Soil type, pH, light and temperature all affected *V. adunca* germination. Highest germina-

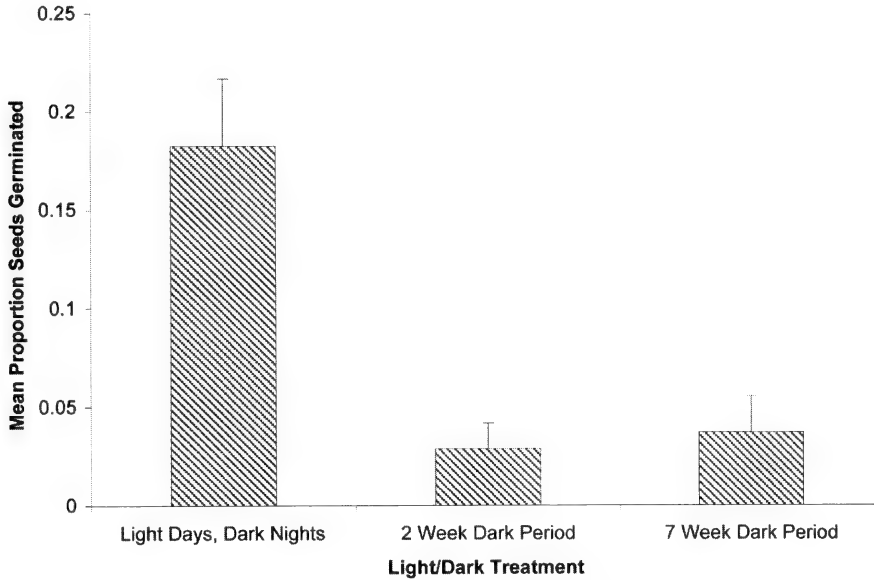


FIGURE 5. The effect of light treatment on proportion of *V. adunca* seeds germinated in Trial 2. The seeds represented in the first bar were subjected to light days and dark nights during the entire experiment (Treatments 1, 3, 5, 7). The seeds represented by the second bar underwent a two week period of constant darkness prior to being placed in the greenhouse (Treatments 2 & 4). The final bar represents seeds that underwent a 6–7 week period of constant darkness prior to being placed in the greenhouse (Treatments 6 & 8). Seeds treated to alternating light-dark periods germinated at a significantly higher rate than seeds treated to constant darkness. Error bars represent  $\pm 1$  standard error of the mean.

tion percentages occurred during the first germination trial, and seeds appeared to respond best to planting in straight potting soil. That there was a significant interaction between soil type and pH bolsters the result that soil is important in germination success, and suggests that further research is warranted to tease apart differences in the soil mixtures and the interaction between pH and soil type. Higher germination percentages in Trial 1 could have been due in part to the fact that in Trial 1, even the control plants underwent a period of cold stratification. Alternatively, soil mixture may simply be the most important factor for *V. adunca* germination success.

Slightly higher pH values resulted in higher germination success. Upon reflection, this result was not surprising. Prescribed burns on the Oregon coast have resulted in higher germination in *V. adunca* (Pickering et al. 2000) and when burns change soil pH, generally the result is an increased pH (Rhoades et al. 2004; Murphy et al. 2006). In west coast forests, *V. adunca* is generally found in meadows rather than amongst trees. Its habitat is early successional; eventually coniferous forests colonize the meadows (USFWS 2001). Disturbances such as fire create a mosaic of meadow habitat that can be colonized by *V. adunca* and

other herbs. Thus it is likely that *V. adunca* is less well adapted to the lower pH values typical of a coniferous forest.

We suspect that the negative result of light/temperature treatment in the first trial may have been an anomaly, either due to the small sample size from the aforementioned error, or because all seeds in the first trial underwent an initial cold stratification period, which may have been sufficient for germination of those seeds.

During the second germination trial we controlled for soil type and pH to more clearly elucidate the relationship between germination and light/temperature. The most striking result was the significantly higher germination percentages with the inadvertent fluctuation in temperature (in the malfunctioning growth chamber). This suggests that fluctuating temperatures, which can occur during seasonal change, may result in higher percentages of germination. Doohan et al. (1991) showed that in a controlled environment, *V. arvensis* germination was highly favored by cool, diurnally fluctuating temperatures, while reduced germination in the field was attributed to an induction of dormancy by high soil temperatures. Alternation of temperature, while not important for germination of many species (Ghersa et al. 1992; Jones et al. 2004; Leon et al. 2004), enhances germination in others (Cochrane et al. 2002; Benvenuti et al. 2004; Leon et al. 2004). It may be that amplitude of temperature alternation is more important than actual temperatures (Leon et al. 2004). In our experiment, a single temperature fluctuation with very high amplitude appears to have sufficiently increased number of seeds germinating. Other germination research suggests that temperature and temperature fluctuation may be the most important cues for seeds to germinate (Baskin and Baskin 1998).

Light requirements can vary between species (Baskin and Baskin 1985) and even within a species depending on the age of the seed (Baskin and Baskin 1995). Other researchers have found that a dark period can enhance *Viola* germination (Doohan et al. 1991). *Viola arvensis* appears to prefer light periods such as would be found in disturbed sites (Baskin and Baskin 1995). Short periods of darkness did not increase germination percentage in *V. adunca* and our data suggest that an extended period without light inhibits germination in this species. A dark period has been found to be relatively unimportant in other studies as well (Burgess et al. 2002).

Overall, soil mixture and temperature fluctuation appeared to influence *V. adunca* seed germination more than the other factors we tested. Our results suggest several areas of future research. For example, further experimentation on the interplay between soil type and pH would help us understand the conditions of each factor that are preferred by *V. adunca*. A comparison of *in situ* conditions vs. controlled growth chamber/greenhouse germination would help to determine a more precise light and temperature regime. Fluctuating diurnal temperatures as well as a gradual increase of temperature over time to simulate seasonal changes could facilitate greater understanding of the germination requirements for this species. Such experiments help us understand of specific life history strategies, and have the potential to improve the efficiency and success of restoration and management.

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## A MARQUETTE COUNTY WISCONSIN SAVANNA REEXAMINED

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### ABSTRACT

An oak savanna surveyed in 1968 was resurveyed in 1989. In the earlier study, we concluded that the site had remained as savanna in the absence of fire due to interacting climatic, edaphic and biotic factors. Since 1968 the site has had some losses and replacement of canopy trees, but has not become a denser closed forest. Many of the oldest trees of 1968 were lost to oak wilt or to storm damage resulting in a drop of one third in the average dbh and about two thirds of BA/ha. Replacement of the oaks is mainly by black cherry clustered on the sites of the dead oaks. Oak seedlings are more evenly distributed and still comprise 70% of seedlings, but generally lack vigor and have high mortality. It appears that this stand will remain a savanna; the grassy open areas will probably remain open with some oak seedlings as well as cherry growing to canopy height as replacements of canopy oaks.

**KEY WORDS:** Oak wilt, Oak savanna, Dry Wisconsin Prairie

### INTRODUCTION

*This work was written based on 35 years of research done by my late parents on a small area of savanna adjacent to the sand county farm they bought in 1955. The paper was originally submitted to The American Midland Naturalist for publication in 1991 and returned with suggestions for minor revisions. My father died in June of that year before returning the paper. Had you ever seen his desk in Lapham Hall, you would understand why the paper remained missing until my mother found it and gave it to me to "rework" shortly before her death in 2005.*

*My parents were raised in northern Illinois and met at Northern Illinois University in 1938. Both got their Bachelor degrees there and returned to school at UW-Madison after the war for advanced degrees. Though her degrees were in the field of English, my mother worked alongside my father on field work from 1939 until his death, helping collect data for his masters' and dissertation research (the latter under Curtis at UW-Madison) on species associations of prairie remnants in Wisconsin and Illinois. Both were experts in species identifi-*

*cation. Our old sand farm and its long term management and use for research were (and still are) inspired by my parent's brief association with Aldo Leopold, his family and farm, made famous in "A Sand County Almanac" (Leopold 1949). That legacy was passed down to me and my sister along with the farm.*

Oak savannas, also called "oak openings," were common in southern and central Wisconsin at the time of European settlement, mainly in the broad ecotone between true prairie grasslands and true forest of moister northern and eastern regions. Generally, these savannas were cleared early for agriculture or were grazed by domestic cattle, so that nearly all were denuded or greatly changed before 1900. Thus Curtis (1959) stated, "Beyond question an oak savanna with intact ground-layer is the rarest community in Wisconsin today," and in an earlier work (Curtis 1956) he discussed in detail the processes by which man had changed vegetation in the region. Savanna sites which were not plowed or grazed commonly become closed forests, a fact often cited in support of the theory that the oak savanna was a subclimax community maintained only by frequent fires set by native Indians (Cottam 1949, Curtis 1959, Sauer 1950).

This study deals with one stand located in Marquette County, WI (Lat. 43° 53' N., Long. 80° 20' W.; Section 6, T16N, R10E) on a site recorded in the U.S. General Land Office Survey in 1851 as "openings, timber black and white oak. No undergrowth." In 1968, having observed this particular site frequently for some years, we noted that there was no sign of fire (fire scars, etc.) having occurred for at least 50 years, but also that there had been no obvious change in tree canopy, seedling or sapling density, or understory. The understory was dominated by herbaceous species, mostly of prairie or "barrens" affinity. Therefore, we initiated a detailed survey to document its stability and to look for possible controlling factors.

The site is approximately three ha, located on nearly level glacial outwash with loamy sand soil, identified by Peck and Lee (1961) as Oshtema-Gotham series. Climate is temperate continental with mean annual rainfall of 79 cm, mean July temperature of 21 C and mean January temperature of about -10 C. The site lies near the southern margin of the "transition zone" between the prairie-oak forest region and the northern conifer-hardwood region, as defined and mapped by Curtis (1959). The climate is highly variable in the annual rainfall, snow cover, and frost-free days; both drought and frost often occur during the average growing season of about 25 May to 5 September, while severe wind storms, hail, lightning, or freezing rain may damage trees almost any year.

The earlier study (Whitford and Whitford 1971) indicated canopy trees of three essentially even-aged size classes: a few large survivors of the original pre-settlement savanna; about two-thirds with origins dating to roughly the first decade of white settlement (circa 1835-1845), and less than one-fourth of more recent origin. Density and BA/ha were well under half those typical of mesic closed forests in Wisconsin, but 75-90% of values given for xeric forests in southern Wisconsin by Cottam (1949) and Curtis (1959). Canopy cover of about 40% and heights averaging 45 ft (13.7 m) as well as low density put this stand in savanna or "woodland" category rather than forest (Dyksterhuis 1957). Thus, in

spite of an apparent increase in tree density related to early settlement, the canopy had, in 1968, remained relatively open and increase in density had been very slow or none in the past century. The stand had reached another level of stability rather than succeeding to a typical closed forest as postulated by Curtis (1959) and others. The size class structure of the stand, very low in 10–25 cm dbh classes and almost lacking in saplings, was distinctly different from that of typical forest sites.

Since the 1968 survey, sporadic casual observations of this site indicated further changes not anticipated by the earlier study, mainly due to severe losses of canopy trees from oak wilt (*Ceratocystis fagacearum*) with replacement mainly by black cherry (*Prunus serotina*). Yet, it remains similar in aspect to the savanna described in 1971, so we resurveyed the site in 1989 to document the changes and reassess its relative stability.

#### METHODS

As in the 1968 survey, we analyzed canopy trees (>10 cm dbh) by the point-centered quarter method (Curtis 1959) at 30 points (120 trees), seedlings and saplings in 40 random quadrats, each 2 × 2 m, and ground layer species in 40 quadrats of 1-m square. Height of 10 random individual oak canopy trees was measured with an Abney hand level and canopy cover was estimated using a hand-held sighting grid (the same observer estimating in both 1968 and 1989 surveys). Because of the observed mortality, in the 1989 survey we also noted standing dead trees or stumps judged to have been cut in the past 20 years if they were closer than the nearest live tree in each compass quarter, i. e. where the tree's death resulted in greater point-to-tree distance.

*Terminology and measures used are the same as those in the original 1971 paper so that data reported are directly comparable between studies. Basic measures used are common to forestry and early ecological assessment studies and each is briefly explained below:*

**DBH** *Diameter at breast height. This is a standard measure of tree size used in forestry. Breast height is standardized as 4.5 feet above the ground.*

**BA/ha** *Basal area/hectare. Calculated as the sum of cross sectional area of all tree trunks at one foot above ground level (usually for a given species) within a one hectare area. Used with the dbh information, it provides a means to clearly describe stand density, age, and relative species abundance.*

**I.V.** *Importance Value. This again is a single number that is meant to provide a reader with appropriate background an ability to glean a mental image of the area described in terms of species present, their relative numbers and sizes. This single number is calculated for each major species in the study area as the sum of three values: relative density, relative frequency, and relative dominance. Each of those numbers is expressed as a percent value based on the total for that species for all sites sampled. Thus I.V. must always be a number between 0 and 300 since that represents the minimum and maximum values possible when adding from three groups totaling 100% each. Sampling was by quadrat method where cardinal compass directions are used to form four quadrats*

around a randomly chosen sample point. Distance to the nearest tree in each quadrat is measured and its species name and dbh is recorded. The species of the tree with the greatest measured canopy area in any of the four quadrats is also recorded. Thus, relative density for a species is the fractional percentage of total sample plots where that species was considered the species with the greatest stem density for the four quadrats sampled. Relative frequency for a species is an expression of the number of sample sites where an individual of that species was the tree closest to the plot center, expressed as a percentage of the total number of sites sampled. Thus, if 34 of 100 plots had a red oak tree as the nearest tree of the four trees used to define the plot, that species would have a relative frequency of 34.0. Relative dominance is an expression of the number of sample sites (of the total) where a given species was designated as the dominant canopy species within the four quadrants. Thus, percent of total plots where Hill's oak was the dominant canopy species is its relative dominance.

## RESULTS

The most obvious change in canopy trees is the decline of both Hill's and red oaks (*Quercus ellipsoidalis* [*Q. coccinea*] and *Q. borealis* [*Q. rubra*]) and some hybrids (Table 1). This resulted from oak wilt, which severely affected the stand starting in the early 1970's. Replacement is mainly by black cherry, which now shows 31.6% relative density. One red pine (*Pinus resinosa*) was present in 1968

TABLE 1. Summary of tree data from quarter method samples. Table values shown below are approximate due to omission of one red pine, and one white pine, from point-centered quarter plot data used for constructing the tables for 1968 and 1989, respectively. Values shown from quarter plots are reproduced directly from the original manuscript. R. Dens. = relative density, R. Freq. = relative frequency, R. Dom. = relative dominance, I.V. = importance value.

Species	Sample of 1968				Sample of 1989			
	R. Dens.	R. Freq.	R. Dom.	I.V.	R. Dens.	R. Freq.	R. Dom.	I.V.
Hill's oak*	66.7	60.5	61.4	188.6	49.2	39.0	54.4	142.0
Red oak	31.6	35.5	38.0	105.1	12.5	19.0	22.7	54.2
White oak	1.7	4.1	0.6	6.4	3.3	6.0	5.8	15.1
Black Cherry	—	—	—	—	31.6	32.0	11.9	75.5
Red pine	—	—	—	—	2.5	3.0	3.7	9.2
	100	100.1	100	300.1	99.1	99.0	98.5	296
Density:	Trees/Acre	91.9	Trees/ha	227.1	Trees/Acre	67.7	Trees/ha	167.3
Basal area:	BA/Acre	95.2 ft <sup>2</sup>	BA/ha	21.87 m <sup>2</sup>	BA/Acre	29.5 ft <sup>2</sup>	BA/ha	6.77 m <sup>2</sup>
Average BA/tree:	148 in <sup>2</sup>		956.9 cm <sup>2</sup>		62.8 in <sup>2</sup>		405.2 cm <sup>2</sup>	
Average dbh:	13.7 in		35.1 cm		8.95 in		22.7 cm	

\*Hill's oaks are mainly *Q. ellipsoidalis* but may include hybrids.

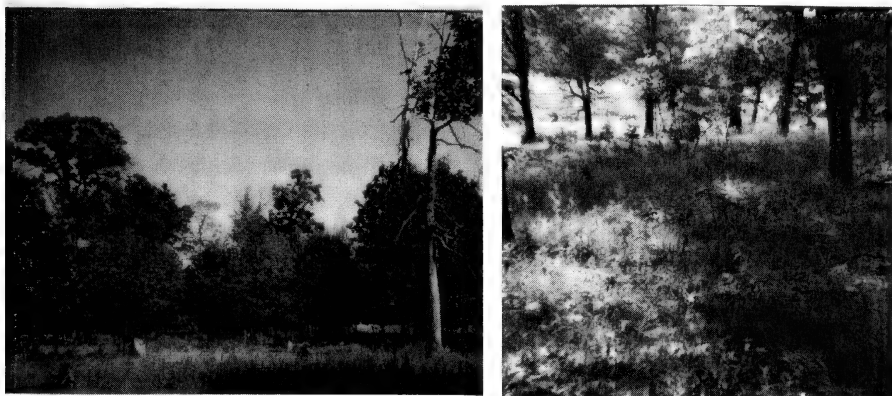


FIGURE 1. A. Oak savanna, Marquette County, Shields Township, Section 6 in 1968. B. Same location in 1989. Photographed by P. B. Whitford.

but was not included in the sample; in 1989 two red pines and one small white pine (*P. strobus*) were tallied.

Average BA is now less than one-half that of 1968 and average dbh has now dropped by one-third. Density (trees/ha) declined by more than one fourth (Table 1). Density of seedlings and saplings was  $0.97/\text{m}^2$ , of which over three fourths were  $<1/2$  m tall; this compares to  $0.89/\text{m}^2$  in 1968, an increase of  $<10\%$ . Oaks comprised 70% of the seedlings sampled and black cherry 27%. Many of the larger oak seedlings showed partial die-back, as noted in 1968, and some were completely dead.

Herb data showed the three species of highest frequency in 1968 (*Carex pensylvanica*, *Euphorbia corollata* and *Amorpha canescens*) are still highest and in the same order, while most of the other species common in the first survey are still present, most in the same magnitude of frequency as before.

## DISCUSSION

Oak wilt infections developed at a few sites in this stand by the early 1970's. These have continued to spread slowly, though we have no data on dates or numbers of trees dying each year. Most dead trees were removed within a few years after death for salvage as firewood. In the 1989 survey our tally of dead trees and stumps within the sample area showed that 21 points of the 30 sampled had a total of 34 dead trees and stumps, which gives a good indication of the extent of loss. At least one tree was killed by lightning during that time and others may have been injured by wind or ice storms or lightning, which would provide entry for the spores of the oak wilt. The data on diminished tree density and basal area noted above reflect the severe loss of the older oaks during this period.

Oak wilt is apparently an endemic fungal disease in this region (Curtis 1959). It is normally fatal to red or Hill's oaks, which together made up over 99% of BA

for the study site in 1968, and both species show severe declines in both density and dominance by 1989. White oak (*Q. alba*) has some resistance to the wilt organism and has doubled in importance value (6.4 to 15.1) between the first and second sampling.

Replacement of the oaks is mainly by black cherry, which in 1968 was noted as one tree in the stand but not tallied in the sample. This species is common on surrounding lands as scattered trees along fences, roadsides and any open untillled sites. Presently black cherry has 31.6% relative density, although these are small young trees and make up only 11.9 % of relative dominance. Since most of the oaks lost were canopy trees of >25 cm dbh, there is a severe decrease of about one-third in average dbh, while average BA is now <1/2 that of 1968. This decrease in average size, combined with the loss in trees/ha (227 to 167), results in a drop of about two-thirds in BA/ha. Surprisingly, the average of estimated canopy values has dropped by less than one-fourth i. e. from 40% to 31.2%. This evidently reflects the low canopy value relative to BA noted in the stand in 1968 (see Whitford and Whitford 1971), which showed much loss of branches due to varied storm damage over the years. The greater vigor and rate of growth of the younger remaining trees now maintains a relatively greater canopy.

The importance of black cherry as a replacement species is not surprising; it is common in the area around this stand and produces abundant fruits which are readily and widely dispersed by birds. The seeds apparently can survive for years dormant in the soil and germinate quickly when increased light and warmer soil follow loss of canopy. Its shade tolerance is rated as intolerant to intermediate; young seedlings are more tolerant and can survive in partial shade for some years until released (Curtis 1959, Auclair and Cottam 1971). Both seedlings and saplings grow vigorously given enough light, so that saplings may reach 10 cm dbh and 7 m in height within 15 years. For these reasons Auclair and Cottam (1971) stated that "black cherry occupies a key position in the oak forest of southern Wisconsin."

It should be noted that the cherry invaders tend to be in rather dense clumps on sites where oaks had died within the past 20 years. Very few cherry seedlings or saplings were found in the larger, older openings where herbaceous species were dense. This may reflect uneven distribution of the seed bank, with most of the seed deposited by birds under former perch trees; it may also reflect less root competition with herbs where canopy of the now-dead oaks had inhibited ground-layer species. Oak seedlings were more evenly distributed and comprised 70% of all seedlings tallied, although most were small (<1/4 m tall).

It appears that very few tree seedlings in the open grassy areas of the savanna survive to become saplings and finally canopy trees. As noted above, and in results in the earlier paper, many larger seedlings showed partial die-back, some were completely dead, and few appear to survive beyond about .5 m in height. Our conclusion in 1971 suggested a very high mortality of seedlings. We believe the edaphic condition of droughty, nutrient-poor outwash sand retards growth and reduces vigor, which is compounded by competition and possibly allelopathic effects of dense sedge/grass/forb competition in the openings. Further, the micro-climate in this low, nearly level site is basically a broad "frost pocket"

where cold air settles in on clear still nights. We have often observed frost damage in these low sites in early June and once as late as July 5.

The frost damage blackens half-developed to nearly mature leaves of the seedlings while the older higher canopy trees are not damaged, nor are those on higher ground. Seedlings already barely surviving from drought or edaphic and biotic factors may be killed by one or more such late frost events. While deer are abundant in the area and do tend to browse tree seedlings, they do not seem to be a major factor here, as most of the dead branches show intact buds at the tips.

Our conclusion of high mortality of seedlings seems to be true. It would be nearly impossible to pinpoint a single causal factor, but the net result is the tendency of savanna openings in such sites in central Wisconsin to remain open.

It appears that this stand, despite changes recently initiated by oak wilt, will remain a savanna in the foreseeable future, with an increase in the proportion of cherry in BA and I.V. totals and with the cherry mostly grouped in sites which had been under oak canopy in 1968.

The larger openings will probably stay open and grassy and the larger oaks will probably continue to decline slowly in the numbers with some oak saplings as well as cherry eventually growing into the canopy at the edges. Fire is not needed to prevent closure of the forest under this combination of factors and with oak wilt apparently periodically removing trees and assuring that only widely spaced oaks without overlapping roots (which permit the disease to move from tree to tree and achieve 100% kill in dense growth situations) survive to form the dominant canopy trees of a largely self-perpetuating sand country savanna opening.

### *Epilogue – 2007*

*Drought conditions of 2004 and 2005, coupled with summer power line clearing efforts that limbed nearby oaks leaving them susceptible to oak wilt spore contamination, have resulted in a third outbreak of oak wilt in the study site and several adjacent areas. From the 1989 data collection to the beginning of the most recent oak wilt infestation the study site retained the relatively open canopy, grassy understory, and limited sapling survival described in my parents manuscript. As such, it still has the characteristic appearance of the dry sand-based savanna I recall from my youth and from the 50 years I have walked it regularly since we first bought the farm. What stands out most in hindsight and fifty years watching the effects of oak wilt is the difference in mortality between dense stands of young oaks that have sprung up in abandoned fields and fence lines on our property and that of neighbors, and that of the savanna oaks. Oak wilt regularly approaches a virtual 100% spread and kill in those dense stands of disturbed sites where overlapping root masses can carry the fungus tree to tree. Yet, in the open savanna, like that my parents researched, the canopy trees are widely spaced with intervening dense grass, sedge and forb communities. Their work implied that this dense herbaceous understory limited sapling size and survival (and thus sapling root spread). If that is true, as it appears, then the dense herbaceous cover essentially assured that roots of canopy trees would not overlap with those of other oaks that might spread the fungus to and/or between them. In my experience and observations it has only been the recently damaged*

*canopy trees that develop oak wilt and die in the savanna, while I've watched all of the 50–60 year old oaks of our third mile long west fenceline die enmass in the space of less than 4 years. What accounts for the difference? On that once over-pastured, disturbed, fence line plot average distance between mature oak trees was less than 30 feet—assuring continuous root to root transmission of the disease.*

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## FOREST COMPOSITION STUDY OF THE GREAT LAKES COASTAL FOREST AT WARREN DUNES STATE PARK, BERRIEN COUNTY, MICHIGAN

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### ABSTRACT

A forest composition study of Warren Dunes State Park (WDSP), located in Berrien County, Michigan was undertaken to document the relative dominance, relative frequency and importance values of the tree species occupying the upland forested dune areas. This study was part of a larger vascular plant study conducted by Smith (2006), and Smith and Woodland (2006) at WDSP. Quadrat analyses were conducted in the northern third of the park in 2005, to repeat a study conducted in 1979, by two distinguished botanists: John R. Wells and Paul W. Thompson. A point-centered quarter method using transects was used to analyze the entire forested dune area at WDSP. The results of the quadrat analyses of the northern section of the park showed an average of 15 trees per quadrat with an average basal area of 900 cm<sup>2</sup> in 1979, whereas in the 2005 study, an average of 12 trees per quadrat with an average basal area of 947 cm<sup>2</sup> was measured. The average basal areas indicated that the trees are larger than they were in 1979, with fewer trees per unit area. The quadrat study demonstrated the trees of the northern forested section of the park reflect a stand that has continued to mature with fewer and larger trees, and that the species composition has not dramatically changed over the last quarter of a century.

After conducting the quadrat analyses on a third of the park area, it was apparent that the individual quadrat comparisons would not be possible because the exact plot boundaries of the original studies could not be ascertained. Therefore, an alternate method using transect data was used to document the forest composition of the entire upland forests of WDSP. The quantitative information provided by the transect analyses of the forested dunes demonstrated that *Quercus rubra* and *Acer saccharum* were the most important species across all eight transects, with importance values of 78.0 and 70.2, respectively. The quantitative results, demonstrated that the forested dune area of the park (which constitutes the majority of the forested land at WDSP), was different than other nearby coastal forests and forests located just a few miles further inland or to the south of WDSP on the southern shore of Lake Michigan. This study also provides an important baseline survey of the forest composition before the invasion of an insect, the emerald ash borer. This beetle has killed the majority of the ash trees (*Fraxinus* spp.) in the eastern part of the state and was documented at WDSP in 2005, as this study was concluded.

### KEY WORDS

Berrien County, Michigan, Quadrat, Point-Centered Quarter, Warren Dunes State Park

### INTRODUCTION

A forest composition analysis was conducted at Warren Dunes State Park (WDSP) located in the west central portion of Berrien County, Michigan on the

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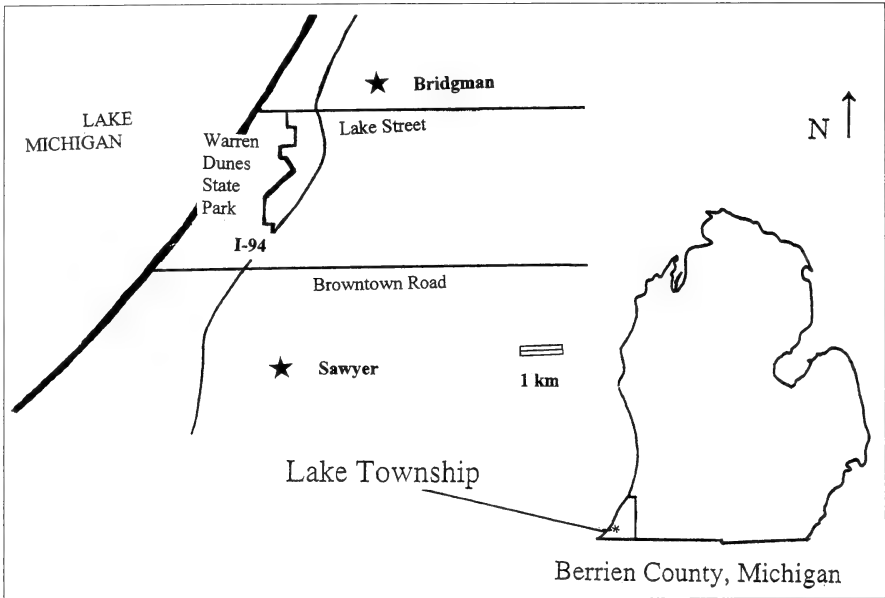


FIGURE 1. Location map of Warren Dunes State Park in Lake Township, Berrien County, Michigan.

shore of Lake Michigan, just south of the town of Bridgman: T6S; R.20W; Sec. 24–26, 35–36 (Figure 1). The park area includes 789 hectares (1,950 acres) of land and roughly 5 km of Lake Michigan shoreline. All of the park lands lie within approximately 2 km of Lake Michigan.

The forest composition analyses were part of a larger study conducted by Smith (2006), and Smith and Woodland (2006), which included a vascular plant inventory of WDSP. The floristic study conducted by Smith and Woodland (2006) demonstrated a high degree of diversity for vascular plants compared to other areas in the region. The high number of different vascular plant taxa (725 taxa) is thought to be the result of a combination of the unique climatic, geographic, and topographic characteristics resulting from the location of WDSP on the southeast shore of Lake Michigan. Smith and Woodland (2006) documented 61 native tree taxa within the boundaries of WDSP out of a total of 88 taxa listed by Dickman (2004) for the entire state of Michigan. The proximity to such a large body of water and the direction of the prevailing winds have resulted in moderated extremes in temperature fluctuations compared to other nearby areas, creating a unique weather regime. In addition, the substrate that the vegetation has developed upon, which includes the undulating ancient sand dunes that are now stabilized with forests, creates a unique topography of steep valleys and serpentine ridges. A detailed discussion of the history, geology, climate and soils of WDSP are included in Smith (2006).

According to Dickmann (2004), forests covered 95% of Michigan before European settlements began. Southern Michigan has suffered the highest losses in forest cover since that time with only 21% of the southern lower peninsula of

Michigan currently covered with forest (Dickman 2004). Since WDSP was set aside in the early part of the 20<sup>th</sup> century, a comparatively minimal amount of development and resource harvesting has occurred within the boundaries of the park. This aspect makes this a desirable area for a baseline forest assessment. Previous studies in WDSP indicated that sections of the park contain virgin stands (Wells & Thompson 1982) and old growth trees (Kost et. al. 2002, Wells & Thompson 1982). However, it is likely that parts of the forested areas of the park were harvested. A plat map from 1873 clearly shows two logging piers on lands that are today part of WDSP (Figure 2). Another map from the Atlas of Berrien County circa 1860 shows four logging piers located within what is now WDSP. The piers are shown on both maps as being connected to horse-drawn railways with docks that extend out into Lake Michigan, indicating that some of the timbers and other products were likely being transported to steamships by way of these railways. It would thus seem likely that some of the timbers would have been harvested from the WDSP area.

The goal of this forest composition study was to provide quantitative data to determine species richness, as well as the frequency, dominance and importance of each of the tree species in the upland forested dune area at WDSP. The upland forests make up the majority of the forested area at the park. There is a smaller amount of lowland forested areas that were not included in these analyses. A digital orthographic photograph provided in Figure 3 shows the topography of the park. The north boundary of the park is represented by the top of the figure, the south boundary is located approximately at the bottom of the figure. The west is bounded by Lake Michigan, and the east boundary is represented by Red Arrow Highway for the most part in the south and central part of the park, while in the northern section of the park, the east boundary is located just west of Interstate 94, as indicated on Figure 3. The dune topography that underlies these forests is visible on the figure. These coastal forests have developed on dunes that formed after the retreat of the glaciers from southern Michigan many thousands of years ago. The dunes located furthest to the east are thought to be the oldest having formed roughly 9,000 years ago as the last glacial ice sheets retreated from southwest Michigan (Wells & Thompson 1982). These underlying stabilized dunes also formed the extremely deep valleys, varied directional exposures and steep topography that include slopes in excess of 45% (Larson, 1980). Elevations at WDSP range from lake level (176 m in 2005) to 238 m above sea level.

Two studies were conducted previously within the current boundaries of WDSP, and one study was conducted within five miles of the park. These studies included information on frequency, dominance and importance values of tree species (Donnelly & Murphy 1987, Wells & Thompson 1982). Therefore, comparisons could be made between this study and these historical studies. To determine quantitative information on the forested dune area of the park, the preliminary plan was to follow the method of study utilized by Wells and Thompson (1979, 1982), who conducted plot-based (quadrat) surveys of WDSP in the northern section, known as the Mount Edward tract (roughly the northern third of the park). The stated purpose of their study design was to provide data to describe the diversity of the forest and to provide baseline data that could be re-





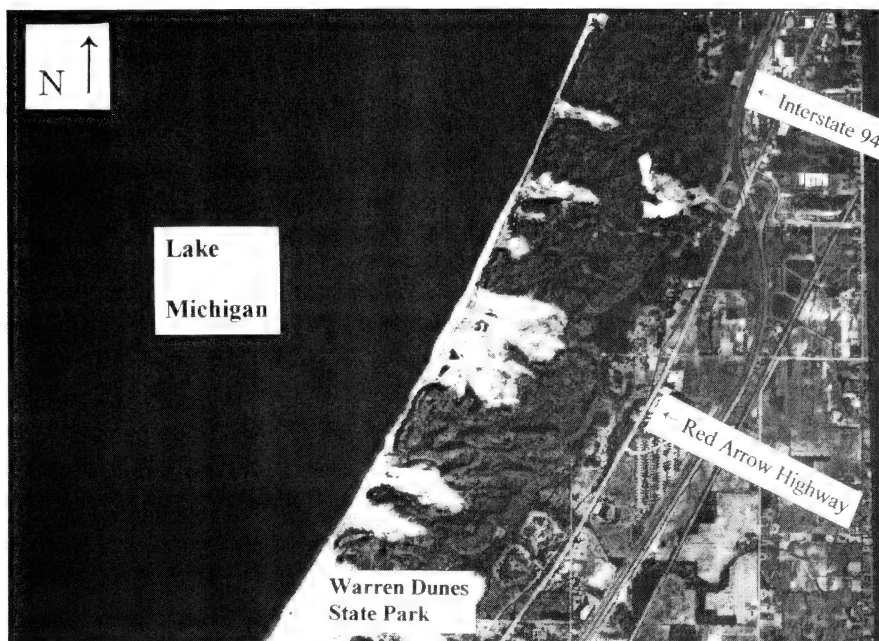


FIGURE 3. Aerial photograph of Warren Dunes State Park, Berrien County, Michigan.

Note: Adapted from 1998 USGS digital orthographic imagery data (downloaded from the Michigan Department of Natural Resources website) showing a portion of the Southwest Bridgman quadrangle.

peated for future comparative work. The intention of this study was to expand the same method to the rest of the park and to quantify the vegetation of the entire forested dune area within the park boundaries. The Wells and Thompson study was repeated to the best of our abilities and the data is presented in this report. However, two serious problems were encountered trying to recreate Wells and Thompson's study. We could not ascertain the exact location of their plots using information provided in both the published and unpublished reports (Wells & Thompson 1979, 1982). We found moving a single plot location by only a few feet dramatically changed the species composition and structure due to the diverse nature of the forested dune area at WDSP. We also found the individual quadrat to quadrat comparisons between 2005 and 1979 data did not yield good information on the forest structure. In addition, the use of non-random plots by Wells and Thompson did not always give an accurate representation of some of the areas surveyed. These issues are explored further in the discussion. As a result of the problems encountered with the plot sampling method used by Wells and Thompson, we selected a method using transects to survey the entire forested area at WDSP. The point-centered quarter method allowed greater efficiency so that the large area of the forested dunes could be surveyed in order to determine the forest structure and composition without the need for permanent plots.

This study was completed before an insect, the emerald ash borer, made its way to the western forests of Michigan, after having decimated populations of ash trees (*Fraxinus* spp.) in the eastern part of the state. Therefore, this study represents a baseline survey before the trees began to die from the infection at WDSP.

The questions we hoped to answer from the quantitative survey included: What trees are most characteristic of this forested dune area in terms of frequency, dominance and importance? Are there differences among the upland forests in the northern section and the southern sections of the park? How does this analysis compare to other analyses conducted in the park or in the vicinity of the park? Are the forests found along the southern coast of Lake Michigan different than those located nearby?

### METHODS

There were two separate forest analyses conducted, one of the studies used plots in the northern third of the park and the second study used a transect based analysis over the entire upland forested area at WDSP. In the northern section of the park, we attempted to recreate the study by Wells and Thompson. Following the Wells and Thompson (1982) methodology, seven 20 × 20 meter plots were set up along north, south, east, and west compass headings. The plots were located in the vicinity indicated by the original report utilizing descriptions and a location map provided by Wells and Thompson (1979, 1982). The approximate locations of these sampling plots are provided in Figure 4. The locations of the plots were provided in the reports by Wells and Thompson as dots on a topographic map and they included a written description of each of the seven habitats. However, it was not enough information to find the exact plot boundaries. We established our plots in the same habitat areas which we believe to be within 5–10 m of the locations of the original plots set up by Wells and Thompson based on the information we had on the slope facings, location and species present. At each quadrat location, flagging tape and a compass were used to delineate 20 × 20 m plots. Every tree with a diameter at breast height (1.4 m) of 8 cm (3 in) or larger was measured and identified in each quadrat. The diameter at breast height (DBH) measurements were used to calculate basal areas for each of the quadrats. The only deviation from Wells and Thompson's (1982) methodology was that the herbaceous layer of the quadrats was recorded only once in this survey, while it was observed several times throughout the growing season in the original study. However, since the only quantitative data reported in the Wells and Thompson (1982) study were basal areas calculated from tree data, a single visit during the growing season was adequate for a comparison between the two studies. The original table created by Wells and Thompson (1979, 1982) was used as a template to create a new table with both the 1979 and 2005 data sets, and is provided in the results section. Descriptions of the areas provided by Wells and Thompson (1979, 1982) were also compared to the data collected in 2005; these data are also provided in the results section.

The quadrat analysis demonstrated that the forested dune area at WDSP is extremely diverse and complicated, as described by Wagner (1979), and Wells and Thompson (1979, 1982). It became apparent that large variations in species composition, even among plots within the same area occurred because the plot sizes were either not sufficiently large or numerous enough to take into account the array of elevations, slope facings, slope grades and varying distances from the lakeshore.

The goal of the transect study was to determine quantitative information on species composition and structure of the forested dunes without the use of permanent plots. A plotless method, the point-centered quarter method developed by Cottam and Curtis (1956) and modified by Mitchell (2001), was selected to provide repeatable quantitative data on the species richness, their distribution through the forest and size of the tree species. The point-centered quarter technique allowed for a large amount of territory to be surveyed that would include these complex associations. Eight transects were placed from the north to the south end of the park, over a distance of roughly 5 km. The approximate locations are shown in Figure 5.

Following the method described by Mitchell (2001), a list of random numbers was generated using a computer program called Research Randomizer (Anonymous 2005a). The random numbers

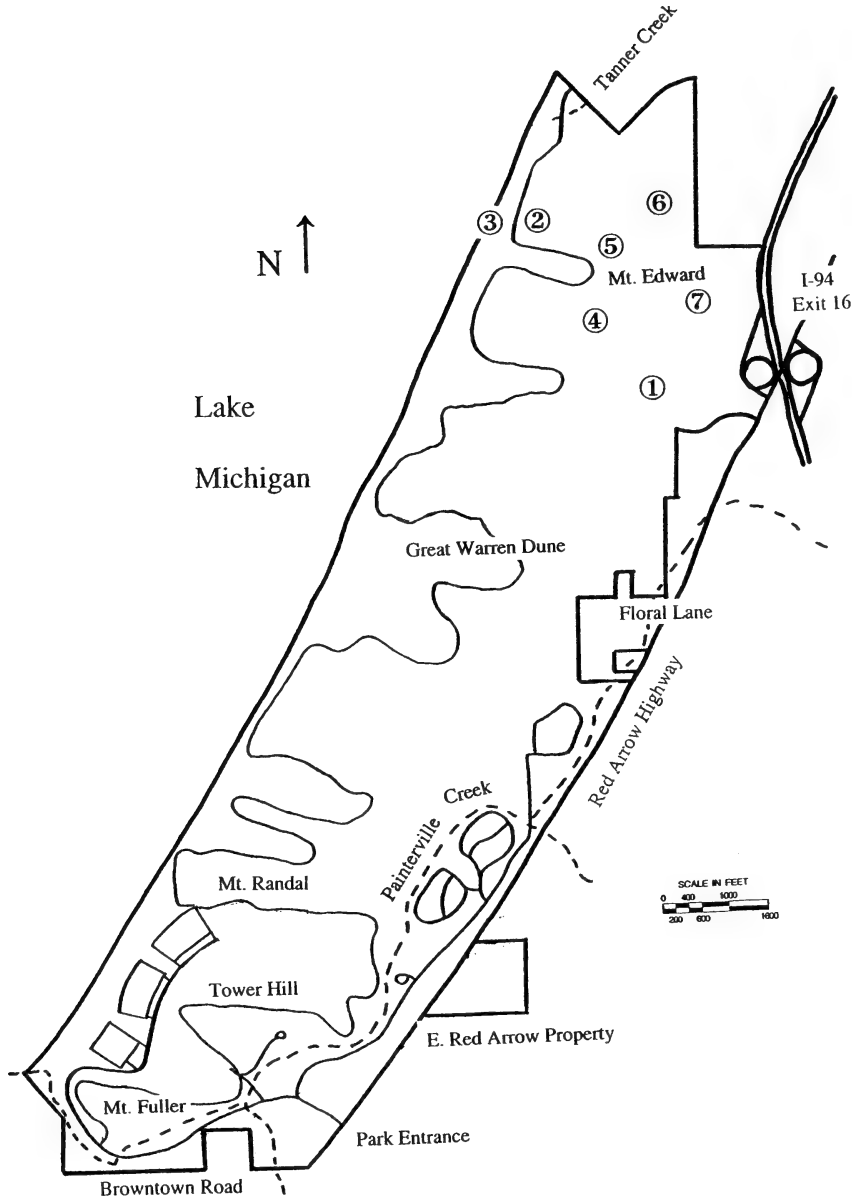


FIGURE 4. Approximate sampling locations for the quadrat survey of the Mount Edward area of Warren Dunes State Park, Berrien County, Michigan, conducted in 1979 (by Wells & Thompson) and 2005. ① —Rich Mesic Forest, ② —Virgin Forest, ③ —Beach Bluff, ④ —Deep Valley, ⑤ —North-Facing Steep Slope, ⑥ —East-Facing Steep Wooded Slope, and ⑦ —Hemlock Stand.

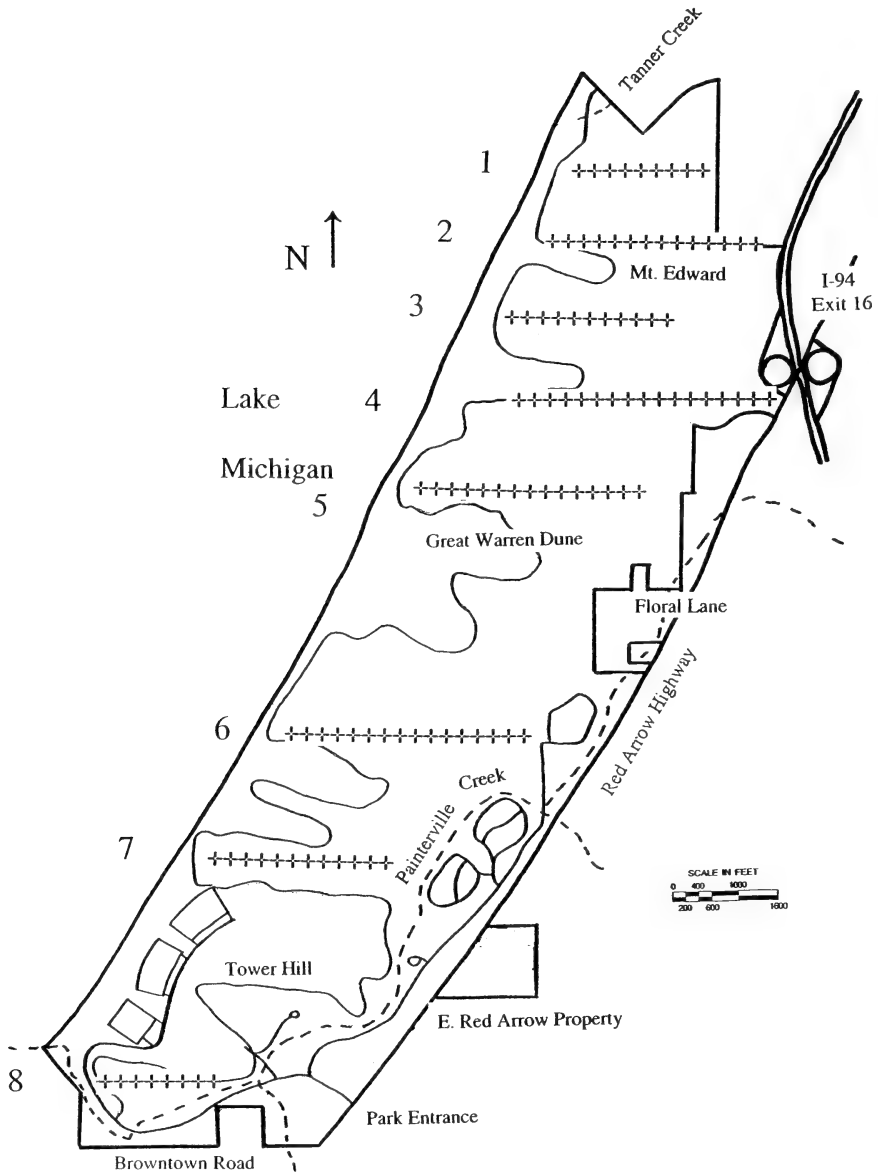


FIGURE 5. Transect locations for the dune forest analyses conducted during September-October 2005, Warren Dunes State Park, Berrien County, Michigan. 1—Weko Transect (Weko), 2—Mount Edward Transect (Edward), 3—Sand Mine Transect (Sand Mine), 4—Church Camp Transect (Church), 5—Great Warren Dune-North Transect (GWD-N), 6—Great Warren Dune-South Transect (GWD-S), 7—Mount Randal Transect (Randal), and 8—Mount Fuller Transect (Fuller).

represented the distances (paces) along each transect at which data were collected. Paces were used to estimate distances in place of a measuring tape, which we found difficult to use due to the length of the transects, rugged nature and often dense understory encountered during the surveys. The random numbers were used to eliminate bias, and were selected so that the sampling points were a minimum of 5 m apart to avoid overlap, and no greater than 20 m apart. At each sampling point, an east-west compass line was used to run an imaginary perpendicular line at the sampling point. The perpendicular line and the transect were used to divide the sampling area into four quarters. Two small dowels attached at right angles marked the center of each sampling point and allowed for visualization of the four quarters. In each sampling quarter, the tree closest to the center sampling point with a diameter at breast height (DBH) of 4 cm or greater, was measured and recorded on a data sheet, along with the species name and the distance from the tree to the center sampling point. This procedure was repeated so that four trees were measured per sampling site. The transects ranged in length from approximately 370–900 m, with the length of each transect dependent on the width of the forest section being traversed. The number of sampling points for each transect varied based on the east-west width of the forest. Eight transects with 299 sampling points yielded a total of 1,196 data points (trees). A species area curve was used to verify that a sufficient number of data points were utilized for the transect survey.

The data were entered onto a spreadsheet to conduct calculations for density, dominance and frequency. Density is calculated by first finding a mean point-to-tree distance for the entire transect. The square of this number is the mean area per tree. The density is calculated by dividing the mean area per tree (after the conversion of square meters) into the unit area (hectares). The relative density for each species is then calculated by taking the number of individuals of a species divided by the total number of individuals, and multiplying by 100. Dominance is calculated by first converting all diameter measurements to basal area and calculating the mean basal area for each species. The basal area equals the density times the average basal area. The relative basal area (or relative dominance) is calculated by taking the relative basal area, dividing it by the total basal areas for all species in the transect, and multiplying it by 100. The frequency is calculated by determining the number of points at which a species occurs along a transect and dividing it by the total number of trees for the transect. Relative frequency is equal to the frequency divided by the total frequencies calculated for all species in the transect and multiplying it by 100. (See Mitchell, 2001 for a more detailed explanation of these calculations). Importance values (I.V.'s) for each transect are then calculated by adding the relative frequency, relative dominance and relative density results for each species to determine the most "important" species.

The data collected for the point-centered quarter analyses also allowed for the calculation of average distances between trees and the average number of trees per hectare for each transect (Mitchell, 2001). Nomenclature for the vascular plants noted in this survey largely follow Voss (1972, 1985, and 1996). Nomenclature for some ferns and fern allies follow Flora of North America (Flora of North America Editorial Committee 1993).

A hand-held Garmin® GPS unit was used to record UTM readings at the center of each quadrat and at the beginning, middle and end of each most of the transects. The GPS unit was not always able to produce readings in the densely vegetated areas.

## RESULTS

### *Quadrat Analyses of the Mount Edward Tract*

The quadrat analyses conducted in the northern section of the park, referred to as the Mount Edward tract, were conducted using the same methodology as a study conducted 26 years earlier (Wells & Thompson 1979). A summary of the data generated for both of these studies, with the basal areas for each tree species, is provided in Table 1. Unfortunately, since we were not able to duplicate the exact locations of the original plots it became apparent from the data in Table 1, that comparisons between individual quadrats, although they were set up within the vicinity of the original plots, do not seem to be meaningful. How-



TABLE 2. Total tree species per quadrat, number of different species, and total basal areas calculated from studies conducted in 1979 (B-1 to B-7) and 2005 (1–7) in the Mount Edward area, Warren Dunes State Park, Berrien County, Michigan.

Quadrat ID 1979	Quadrat ID 2005	No. Species 1979	No. Species 2005	No. Trees 1979	No. Trees 2005	Total Basal Area (cm <sup>2</sup> )	
						1979	2005
B-1	1	3	7	14	13	12,503	14,436
B-2	2	9	3	19	7	17,957	8,591
B-3	3	1	4	6	6	510	3,592
B-4	4	7	5	16	9	12,641	17,088
B-5	5	4	5	12	10	12,872	9,788
B-6	6	7	7	23	19	15,926	9,938
B-7	7	4	5	14	17	21,187	13,291
TOTAL				104	81	93,596	76,724

ever, combining the data of all seven quadrats seemed to yield some comparable information.

Wells and Thompson measured an average of 15 trees per quadrat with an average basal area of 900 cm<sup>2</sup>, whereas the 2005 study results showed an average of 12 trees per quadrat with an average basal area of 947 cm<sup>2</sup> for the seven quadrats. A summary of the total basal areas for each quadrat, the number of trees per quadrat, and the number of different species is provided in Table 2. The average basal areas indicated the trees are larger than they were in 1979, with fewer trees per unit area.

A total of 15 different tree species were recorded in the 1979 study, whereas 18 species were recorded for the 2005 study. The six most commonly encountered tree species were identical between the two studies, and were found in 43 to 71% of the quadrats (Table 3). The three most commonly encountered tree species in 2005 were *Acer saccharum*, *Quercus rubra*, and *Tilia americana*. *Fagus grandifolia*, *Tilia americana*, and *Tsuga canadensis* were the most commonly encountered species in 1979. These may not be significant differences because of issues with the methodology, which will be discussed later. The most notable difference between the two studies that could be of significance is the

TABLE 3. A comparison of the eight most common tree species encountered by the percentage of quadrats displaying each taxon, for the studies conducted in 1979 and 2005, in the Mount Edward area, Warren Dunes State Park, Berrien County, Michigan.

Species	Percentage of Quadrats 1979	Percentage of Quadrats 2005
<i>Acer saccharum</i>	43	57
<i>Fagus grandifolia</i>	57	43
<i>Quercus rubra</i>	43	71
<i>Tilia americana</i>	71	57
<i>Tsuga canadensis</i>	57	43
<i>Sassafras albidum</i>	43	43
<i>Liriodendron tulipifera</i>	43	43
<i>Ostrya virginiana</i>	0	43

presence of *Ostrya virginiana* in 43% of the 2005 quadrats, while none were recorded in 1979 (Table 3).

Wells and Thompson (1979) did not randomly choose their quadrats, but selected areas they thought represented some of the unique communities found in the wooded dunes of the Mount Edward tract. The quadrat data are presented as descriptive information, which is how the data were utilized and presented in the 1979 study. A description of each of the seven quadrats (plots) is provided below.

#### *Rich Mesic Forest—Plot 1 (B-1)*

The rich mesic forest plot was located very close to the edge of a sand mine area that closed in 1977. Quadrat 1 (or plot 1 for 2005 and B-1 for 1979) was selected by Wells and Thompson (1979) as an example of the rich mesic forest type. The common tree species noted in the study site and the surrounding forest in 2005 included: *Acer saccharum*, *Fagus grandifolia*, *Liriodendron tulipifera*, *Ostrya virginiana*, *Prunus serotina*, *Quercus rubra*, *Sassafras albidum*, *Tilia americana*, and *Tsuga canadensis*. Wells and Thompson (1979) recorded 65 different herbaceous plant taxa within their quadrat, noting that the diversity was largely contributed by the spring flora. In 2005, a total of 41 different plant taxa were recorded in the quadrat area during a single site visit. Species of note observed by Wells and Thompson (1979) included *Chimaphila umbellata* and *Habenaria viridis*. These species were not observed in the 2005 study quadrat, but *Habenaria viridis* was documented in adjacent areas. *Chimaphila umbellata* was not found in the study plot, nor was it found in the park during the 2004–2005 floristic survey (Smith & Woodland 2006), although repeated attempts were made to locate this species. This species should have been conspicuous if it was present at the time of the quadrat survey on July 27, 2005. An increment core sample taken by Wells and Thompson from a large *Tsuga canadensis* in this area, indicated this tree was at least 224 years old in 1979. Very large trees were common throughout the forested dunes of WDSP, and provided evidence that many of these areas were not logged, or were selectively logged in the past.

#### *Virgin Forest—Plot 2 (B-2)*

As noted by Wells and Thompson (1979), this area included a number of very large trees that suggest the virgin character of the valley. *Liriodendron tulipifera* and *Tilia americana* were significant dominants in both the 1979 and 2005 quadrats, with *Acer saccharum* a dominant in the 2005 study. According to the 1979 data, *Betula alleghaniensis* was a major component of the overstory, accounting for 29% of the total coverage. Based on this information, one might expect roughly one third of the dominant trees to be *B. alleghaniensis* in this valley or at least in the vicinity of their quadrat. This was not the case, as a matter of fact after comparing the 2005 quadrat data to the 1979 data we re-visited the area. After a thorough search of the entire inner dunal valley, it appears that there were two specimens of *Betula alleghaniensis*. These were very large trees that were not in the area indicated by Wells and Thompson for the location of the plot. However, it does appear that one of these trees was included in the 1979





FIGURE 6. *Betula alleghaniensis* (yellow birch) as photographed in 2005 at Warren Dunes State Park, Berrien County. This same tree was referred to by Wells & Thompson in 1979 and a photograph was published in Wells & Thompson 1982.

quadrat. This specimen was so unusually large that Wells and Thompson even provided a photograph of it in their 1982 report. A current photograph of the same tree was taken in 2005 (Figures 6 & 7). The diameter at breast height (DBH) of the tree noted in the 1979 was 81.7 cm. Therefore, it was this specimen that accounted for the entire basal area reported for *Betula alleghaniensis* for the B-2 quadrat (5,242 cm<sup>2</sup>). The same specimen measured in 2005 was 90.1 cm DBH (basal area of 6,373 cm<sup>2</sup>). This explains why our quadrat did not contain any *Betula alleghaniensis* and is an example of how non-random plot selection makes it hard to interpret results.

#### *Beach Bluff—Plot 3 (B-3)*

The quadrats for this study were aligned so that half of the study plot was in the forested section of a foredune, and half was situated in an area without trees. The 1979 quadrat consisted of six small *Quercus rubra* with a total basal area of 510 cm<sup>2</sup>. The 2005 quadrat included *Q. rubra* along with *Hamamelis virginiana*, *Sassafras albidum* and *Tilia americana*, with a total basal area of 2,420 cm<sup>2</sup>. The non-forested portion of the quadrat was dominated by a beach grass, *Ammophila breviligulata*, in 2005. Another grass species, *Andropogon virginicus*, was noted in 1979, but it was not encountered in 2005. Many of the forest herb layer species were similar between the two plots, including *Euphorbia corollata*, *Smi-*

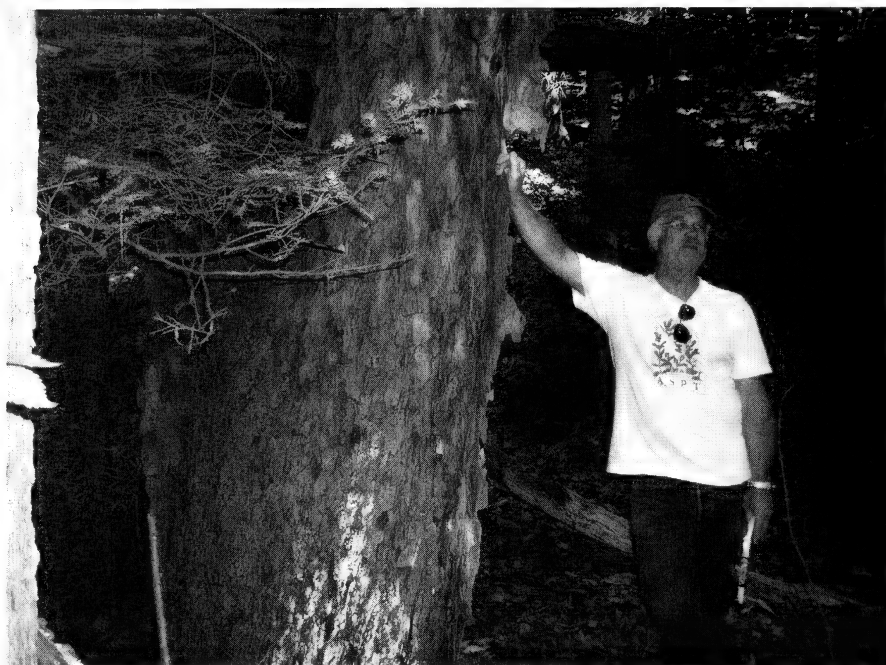


FIGURE 7. Close-up view of *Betula alleghaniensis* (from Figure 6) photographed with Dr. Dennis Woodland for scale, at Warren Dunes State Park, Berrien County, Michigan.

*lacina stellata* and *Solidago caesia*. This area has been highly impacted by recent human activities.

#### *Deep Valley—Plot 4 (B-4)*

This area was selected because of the dense understory of *Lindera benzoin* according to Wells and Thompson (1979). The dominant trees included *Acer saccharum* with 30% cover, *Quercus rubra* with 11% cover, and *Tilia americana* with 15% cover according to the text portion of Wells and Thompson's (1979) study. However, the tabular data were not consistent with the text and showed 46% cover by *Quercus rubra* (Wells & Thompson 1979), which more closely resembled the 2005 quadrat data. The 2005 quadrat located in this area showed 10% *Quercus muhlenbergii*, 68% cover by *Quercus rubra*, and 14% *Tilia americana*. The data from the 1979 and 2005 plots at this location were the most alike in terms of tree species composition of all the plots compared.

#### *North-Facing Steep Slope—Plot 5 (B-5)*

The 1979 study showed 10% *Acer saccharum*, 65% coverage from *Tilia americana*, and 24% coverage from *Tsuga canadensis*, with a relatively small percentage of *Fagus grandifolia*. The 2005 study showed 8% *Acer saccharum*, 54% *Fagus grandifolia*, 32% *Quercus rubra*, and no *Tilia americana*. These data indicated that microgeographic variation in the dune forest composition can be



FIGURE 8. The “Hemlock Pond” area noted by Wells and Thompson (1979) east of Mount Edward at Warren Dunes State Park, Berrien County Michigan, photographed in 2005.

very marked, even when located on similar slopes and directional facings. It is also another example of the limited ability to directly compare quadrat results unless the exact same plot is located.

#### *East-Facing Steep Wooded Slope—Plot 6 (B-6)*

The 1979 study showed 14% *Prunus serotina*, 56% cover by *Quercus rubra*, and 13% cover by *Tilia americana*, while the 2005 study shows 17% cover by *Acer saccharum*, 40% cover by *Liriodendron tulipifera*, and 28% cover by *Tilia americana*. These two quadrats are both east-facing steep wooded slopes in the same vicinity, but clearly the species compositions are not similar between the two studies. This provides a demonstration of the diversity of the tree species composition of the forests at WDSP and the inadequacy of a single 20 × 20 m plot to represent a single locality in a forest of this character.

#### *Hemlock Stand—Plot 7 (B-7)*

The 1979 quadrat data showed 19% cover by *Fagus grandifolia*, 7% cover by *Prunus serotina*, and 69% cover by *Tsuga canadensis*. The 2005 study showed 52% *Fagus grandifolia*, 25% *Quercus rubra*, and 5% *Tsuga canadensis*. This area was particularly interesting because it was near a forested wetland that

Wells and Thompson (1979) referred to as “Hemlock Pond” (Figure 8). They noted this area contained herbaceous species that are reminiscent of Michigan’s boreal flora, including typically more northern species like *Coptis groenlandica*, *Goodyera pubescens*, and *Trientalis borealis*. In addition, they noted *Chimaphila umbellata* and *Maianthemum canadense* as common herbs. In 2005, only *Maianthemum canadense* and *Trientalis borealis* were observed in the area. This area was surveyed on multiple occasions during 2004 and 2005, to locate *C. umbellata*, *C. groenlandica* and *G. pubescens*, but without success.

### **Transect Analyses of the Forested Dunes**

The transects that each traversed the dune area from east to west, allowed a variety of slopes and directional facings to be sampled with more efficiency than quadrat samples, while including habitats with varying proximity to Lake Michigan. The location for each of the transects was chosen based on areas where the long stretches of contiguous forested dune area were available to run the east to west transects at intervals to cover the 5 km north-south length of the park. The estimated transect lengths ranged from 370–900 m with an average of 37 (20–50) sampling sites per transect.

A total of 28 tree species were identified in the transect analyses, with each transect yielding 13–21 different taxa. A species area curve (Figure 9) was generated to confirm that a sufficient number of data points were sampled to adequately describe the forested area of the park. The point where the curve plateaus

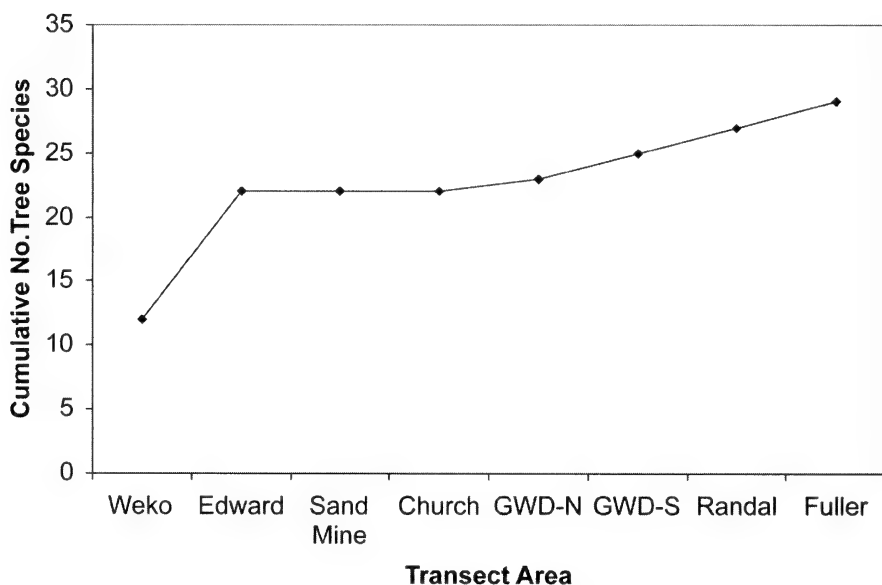


FIGURE 9. Species area curve calculated using the cumulative number of different tree species encountered at each transect from the forest composition study conducted in 2005, at Warren Dunes State Park, Berrien County, Michigan.

can be used as an indicator that a satisfactory number of data points have been collected so that most of the tree species are represented. Figure 9 demonstrates that as more transects were added (as the area sampled increases), the number of new tree species leveled off.

The point-centered quarter data were used to calculate relative frequency, relative dominance, and relative density for each of the eight transects as described in the methods section and following the calculations in Mitchell (2001). These values were then used to calculate importance values (I.V.'s) for each tree species encountered at each transect. Two species, *Quercus rubra* and *Acer saccharum*, exhibited the highest I.V.'s for all eight transects. Both of these species are indicative of the mesic nature of this forest. A summary table of the I.V.'s is provided in Table 4. Estimates of the average distance between trees, species diversity (or richness) and the number of trees per hectare are included in the summary below.

Weko Transect (Weko)

This is the northernmost transect which crosses the forested area close to the Weko Beach area. Based on 29 sampling points, the average distance between trees was 4.7 m, with a total of 432.9 trees per hectare. Out of 116 trees measured, 12 different species were observed. *Quercus rubra* was the dominant

TABLE 4. Importance Values (I.V.'s) listed in order of highest to lowest for each tree species by transect, for a survey conducted at Warren Dunes State Park, Berrien County, Michigan, in 2005.

Species	Weko	Edward	Sand Mine	Church	GWD-N	GWD-S	Randal	Fuller
<i>Quercus rubra</i>	116.2	71.5	64.9	71.3	63.3	83.4	54.3	109.8
<i>Acer saccharum</i>	43.9	53.2	91.8	82.4	66.4	64.9	73.8	55.4
<i>Tilia americana</i>	15.7	11.3	28.8	12.3	42	13.7	53.7	7.4
<i>Sassafras albidum</i>	27.3	23.7	12.2	55.2	23.8	19.1	3.6	22.4
<i>Ostrya virginiana</i>	4.5	30.6	21.3	10	15	33.8	39.1	24
<i>Tsuga canadensis</i>	12.8	23.6		12.1	19	15.4	14.5	10.8
<i>Fagus grandifolia</i>	2.2	12	35.3	5	37.1	6.8	3.1	
<i>Liriodendron tulipifera</i>	32.3	23.3	7.5	10	5.1	14.5		
<i>Quercus muhlenbergii</i>	7.7	8.8	15.2	14.4	5.3	8.7	10.8	7.4
<i>Carya cordiformis</i>	3.4	1.7		8.5	6.6	12.1	11.9	2.9
<i>Pinus strobus</i>		8.1	2.4			7.4	12.9	23.3
<i>Carpinus caroliniana</i>		4.2	4.3	4.6	6.8	1.7	11	
<i>Quercus velutina</i>	15.7	10.8	7.3		3.9			
<i>Cornus florida</i>	17.4	5.1	6.7	5.5		2.4		
<i>Fraxinus americana</i>		2.5		1.9		4	2.9	32.5
<i>Prunus serotina</i>					4.8	6.7		3
<i>Quercus alba</i>		2	4.4	6.9		4		
<i>Celtis occidentalis</i>						2	5	
<i>Ailanthus altissima</i>						3		2.7
<i>Amelanchier laevis</i>		2.7						2.9
<i>Acer rubrum</i>		3		1.9				
<i>Populus deltoides</i>							3.4	
<i>Acer nigrum</i>		3.4						
<i>Ulmus rubra</i>					2.2			
<i>Thuja occidentalis</i>						2		
<i>Prunus virginiana</i>		1.7						
<i>Asimina triloba</i>		1.7						
<i>Betula alleghaniensis</i>						1.7		

species for this transect, and exhibited the highest importance value recorded for all transects. *Acer saccharum* exhibited the next highest I.V. with *Liriodendron tulipifera*, also a significant part of the overstory. The results are provided in Table 4. The terrain in this area, like much of the forested area at Warren Dunes State Park, was very steep with a complex array of slope facings. *Asimina triloba*, *Prunus virginiana*, and *Viburnum acerifolium* formed significant parts of the understory. Although *Juglans cinerea* was not one of the trees sampled, this species was observed in this area and is worthy of note because it is not frequently encountered. One of the drawbacks noted by users of the point-centered quarter analysis method is that it often does not represent uncommon, widely dispersed tree species.

#### Mount Edward Transect (Edward)

This transect was located north of the Mount Edward blowout and south of the Weko transect. The eastern portion of this transect traversed a very steep Algonquin-age dune. Based on transect data of 48 sampling points (192 trees), the average distance between trees was 4.51 m, with an average of 492.6 trees per hectare. *Quercus rubra* was the dominant, *Acer saccharum* had the next highest I.V., with *Ostrya virginiana* the third highest (Table 4). *Asimina triloba*, *Hamamelis virginiana* and *Lindera benzoin*, were common understory species along the transect, with the first two forming dense cover in some areas.

#### Sand Mine Transect (Sand Mine)

This transect covers an area from the eastern edge of the old sand mine to the last forested dune on the western edge and lies to the south of the Mount Edward transect. *Acer saccharum* exhibited the highest I.V., *Quercus rubra* the second highest value and *Fagus grandifolia* the third highest value. *Tilia americana* and *Ostrya virginiana* were also significant forest species. For this transect, 33 points (132 trees) were surveyed; 13 different species were recorded (Table 4) with an average distance between trees calculated to be 4.3 m with 531.9 trees per hectare. *Asimina triloba*, *Dirca palustris*, *Hamamelis virginiana*, *Lindera benzoin*, *Sassafras albidum*, *Smilax rotundifolia*, and *Viburnum acerifolium* were common understory species.

#### Church Camp Transect (Church)

This transect crossed the forested dune area from a ridge just south of the sand mine area to the abandoned church camp area located south of a large blowout. This transect lies south of the sand mine transect. The data showed *Acer saccharum* to be dominant with *Quercus rubra* the next most important species, and *Sassafras albidum* was the third most important species. *Tilia americana* and *Tsuga canadensis* were also important (among the highest I.V. values). A total of 44 points were sampled (176 trees), with 15 different tree species recorded (Table 4). The average distance between trees was estimated to be 4.64 m, with 465.1 trees per hectare. The common understory species included *Asimina triloba*, *Dirca palustris*, *Fraxinus americana*, *Hamamelis virginiana*, *Smilax rotundifolia*, and *Viburnum acerifolium*.



FIGURE 10. Large *Quercus rubra* (red oak) being measured by Lynda Pelkey during the 2005 transect survey of Warren Dunes State Park, Berrien County, Michigan.

#### *Great Warren Dune—North Transect (GWD-N)*

This transect was located on the edge of a wetland area on the east side of the park and crossed the forested area to a foredune to the north of the Great Warren Dune blowout area, south of the church camp transect. This transect included 40 sampling points, or 160 trees. *Acer saccharum* and *Quercus rubra* exhibited the highest I.V.'s, with *Fagus grandifolia* and *Tilia americana* the next highest (Table 4). There were 14 different tree species recorded; the average distance between trees was calculated to be 4.02 m with 617.3 trees per hectare. *Asimina triloba*, *Lindera benzoin*, *Dirca palustris*, *Sassafras albidum*, and *Viburnum acerifolium* were common understory species. An herbaceous species of note encountered during the survey included an uncommon orchid, *Aplectrum hyemale*. A very large specimen of *Quercus rubra* was also among the trees sampled with a DBH of 105.6 cm (Figure 10).

#### *Great Warren Dune—South Transect (GWD-S)*

This transect was located in the more southern part of the park, south of the Great Warren Dune. A total of 50 points were sampled (200 trees) with 19 different tree species recorded. The average distance between trees was calculated to be 4.31 m, with 538.2 trees per hectare. *Quercus rubra* was the dominant

species, *Acer saccharum* had the second highest I.V., and *Ostrya virginiana* with the third highest value. *Sassafras albidum*, *Carya cordiformis*, *Tilia americana* and *Tsuga canadensis* had I.V.'s greater than 10 (Table 4). On the eastern edge, three invasive species, *Alliaria petiolata* (eight sampling points), *Lonicera japonica* and *Vinca minor* (one sampling point each) were noted. A large specimen of *Carya cordiformis* (51 cm DBH) was noted but not sampled as part of this survey. *Asimina triloba*, *Hamamelis virginiana*, *Lindera benzoin*, and *Sassafras albidum* were common understory species, with *Dirca palustris* and *Prunus virginiana* more common toward the western edge of the transect.

#### Mount Randal Transect (Randal)

The transect for this area spanned a forested area (Mount Randal) surrounded by two blowouts, and was located in the south part of the park, south of the Great Warren Dune-south transect. The eastern edge of the transect was located west of Painterville Creek near the southern part of the main campground area, and terminated north of the beach parking lots. This transect contained 35 sampling points (140 trees) with 14 different tree species recorded. The average distance between trees was 4.81 m (the highest value among the nine transects), with 432.9 trees per hectare. *Acer saccharum* was the dominant trees species, *Quercus rubra* and *Tilia americana* exhibited the next highest values and *Ostrya virginiana* was also a significant component of the forest. *Carpinus caroliniana*, *Carya cordiformis*, *Pinus strobus*, *Quercus muhlenbergii*, and *Tsuga canadensis* had I.V.'s greater than 10 (Table 4). *Staphylea trifolia* was a significant part of the understory in some sections, as were *Asimina triloba*, *Dirca palustris*, *Lindera benzoin*, *Prunus virginiana* and *Sassafras albidum*. Other plants of note included *Dryopteris marginalis*, *Taxus canadensis* (severely deer browsed), and *Tiarella cordifolia*.

#### Mount Fuller Transect (Fuller)

This was the southernmost transect in the park. Mount Fuller is a high forested dune that likely receives higher visitor use due to its proximity to the large developed beach area, compared to the transects located further north. The transect contained 20 sampling sites (80 trees measured) with 13 different tree species recorded. The calculated average distance between trees was 3.58 m with 781.0 trees per hectare. *Quercus rubra* was the dominant species, with *Acer saccharum* next highest and *Fraxinus americana* with the third highest importance value. *Pinus strobus* and *Sassafras albidum* were also important overstory species (Table 4). *Staphylea trifolia*, an understory species formed an extremely dense cover on south-facing slopes along this transect. It is interesting to note that Swink and Wilhelm (1994) made particular reference to the population at Mount Fuller as an example of an area where this taxon is "very abundant". *Asimina triloba*, *Dirca palustris*, *Hamamelis virginiana* and *Viburnum acerifolium* were other significant understory species in this area. *Alliaria petiolata*, a noxious weed, was observed at three sampling points along this transect. *Toxicodendron radicans* was a significant component of the herbaceous layer at the edge of the wooded area. A single population of *Polypodium virginianum*, an uncommon fern species, was found during this transect study along a north-facing





FIGURE 11. A Mesic Southern Forest Community at Warren Dunes State Park, Berrien County, Michigan, photographed in 2005.

steep slope on the eastern portion of the transect. *Taxus canadensis* was also noted at several points along the transect.

## DISCUSSION

### *Dune Forest Composition*

The steep terrain of the forested dune area at Warren Dunes State Park (WDSP) has resulted in the formation of a patchwork of plant communities in the valleys and on the different slopes and slope facings. This diversity was initially demonstrated by the study conducted by Wells and Thompson (1979) and a report by Wagner (1979). The natural community inventory conducted by Kost et al. (2002) determined that the forested dunes of WDSP included three forest types: mesic southern, mesic northern, and dry-mesic southern forests. The mesic southern forest (Figure 11) was dominated by *Acer saccharum*, *Carya cordiformis*, *Fagus grandifolia*, *Liriodendron tulipifera*, *Quercus muhlenbergii*, *Q. rubra*, and *Tilia americana*. This forest type covers the majority of the forested dunes at the park. The mesic northern forest (Figure 12) was characterized by similar dominants as the mesic southern forest but also included *Pinus*



FIGURE 12. A Mesic Northern Forest Community at Warren Dunes State Park, Berrien County, Michigan, photographed in 2005.

*strobus* and *Tsuga canadensis*. The dry-mesic southern forest community is less common at WDSP. It was characterized by *Q. velutina*, *Q. alba*, *Q. rubra* and *Sassafras albidum* as canopy dominants. The study by Kost et al. (2002) noted that the oaks growing on the ridge tops in this community type at WDSP seem to have growth forms of trees that were grown in open areas, suggesting that an oak barrens or savanna community existed there at one time (Figure 13). Both the mesic northern and mesic southern forest community types at WDSP are considered by Michigan Natural Features Inventory to be a natural community occurrence, because they are in excellent condition and cover a relatively large area of land (Kost et al. 2002). *Fagus grandifolia* and *A. saccharum* were noted by Wagner (1979) as being confined to the richest portions or valleys of the dune areas, whereas *Q. muhlenbergii* and *Q. rubra* were more common in the higher areas of the dune forest. Wagner also commented on a vine species, *Vitis aestivalis*, that was common in this area that had barely missed being included on the state list of threatened species for Michigan. He noted that it was very common at WDSP but uncommon in the rest of the state. A large specimen was photographed during the quadrat survey in 2005 with a diameter of 13.7 cm (Figure 14).

The herbaceous plants contributed a significant amount of diversity to the

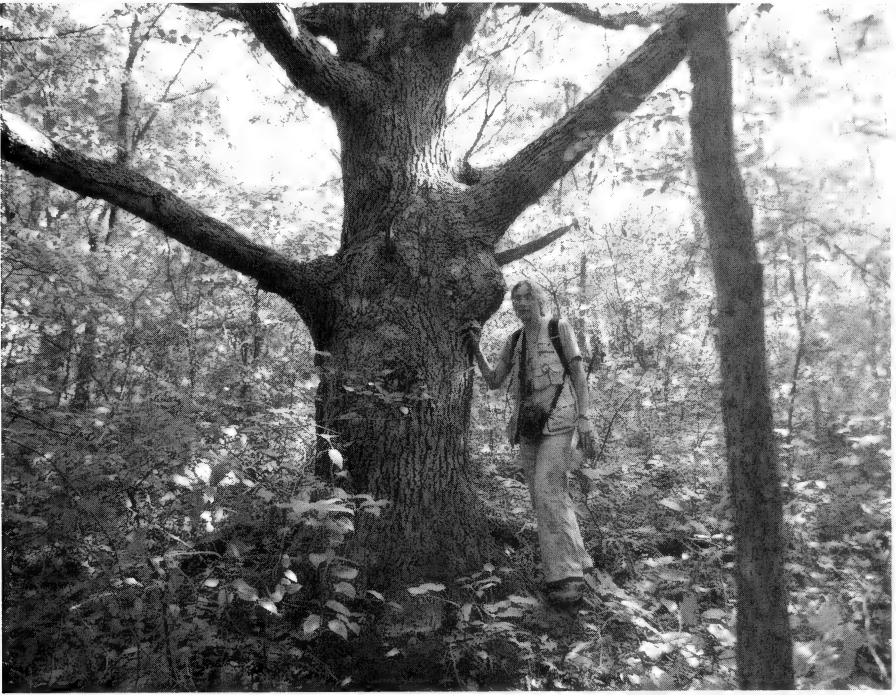


FIGURE 13. A Dry-Mesic Southern Forest Community remnant, showing a mature specimen of black oak (*Quercus velutina*) at Warren Dunes State Park, Berrien County, Michigan, photographed in 2005 with Pam Smith shown for scale.

forested dune habitats. During this survey, as many as 40 different herbaceous taxa were observed in a single day in a  $20 \times 20$  m area. The common taxa included *Aralia nudicaulis*, *Dentaria laciniata*, *Dicentra cucullaria*, *Podophyllum peltatum*, *Trillium grandiflorum*, and *Uvularia grandiflora*. Less common herbs included *Arabis canadensis*, *Arabidopsis thaliana*, *Allium tricoccum*, *Dicentra canadensis*, *Gaultheria procumbens*, *Geranium maculatum*, *Hydrophyllum appendiculatum*, *Lobelia siphilitica*, *Mitchella repens*, *Mitella diphylla*, *Panax trifolius*, *Pedicularis canadensis*, *Polygonatum biflorum*, *Smilax herbacea*, *S. illinoensis*, and *Tiarella cordifolia*. Some rare plants included *Adlumia fungosa*, *Asclepias exaltata*, *Chimaphila maculata*, *Habenaria viridis* and various threatened species. Rare plants have been heavily harvested at WDSP despite attempts to discourage this activity (Goetz 2003). Another state-listed threatened species found in the forested dunes was *Morus rubra*, an understory tree species.

Fern species common in the dune forest included *Asplenium platyneuron*, *Botrychium virginianum* and *Dryopteris marginalis*. Wagner (1979) commented that marginal woodfern, *Dryopteris marginalis*, is an example of a number of plants that reach their southern limit at WDSP because of the proximity of Lake Michigan and its moderating effects on climate. He notes that there is no place



FIGURE 14. Summer grape (*Vitis aestivalis*) with a girth of 13.7 cm as photographed in July, 2005, near quadrat 7 in the Mount Edward area of Warren Dunes State Park, Berrien County, Michigan.

in southern Michigan where this fern is as abundant, and that this species would be treated as rare or even threatened in southern Michigan, but in the forested dunes, especially on steep slopes, it is one of the dominant forest floor plants (Figure 15). Clubmosses encountered in the forested dunes included *Diphasias-trum digitaria*, *Huperzia lucidula*, and *Lycopodium clavatum*. Some of the sedges collected in the dune forest included *Carex albursina*, *C. canescens*, *C. eburnea*, *C. muhlenbergii*, *C. pedunculata*, *C. pensylvanica*, *C. platanginea*, and *C. virescens*. Common woodland grass species collected during this study included *Bromus pubescens*, *Muhlenbergia tenuiflora*, *Oryzopsis asperifolia*, and *O. racemosa*.

The results for both the plot-based quadrat analyses and the transect analyses helped develop a picture of the forested dune area of WDSP. Wells and Thompson's quadrat study was repeated as part of the 2005 survey to compare the two data sets and look at the forest dune composition. The quadrat study demonstrated that each of the seven study plots (quadrats) had different dominant tree species based on calculated basal areas, and a diversity of species making up each sample plot. A comparison between the two data sets showed the six most commonly encountered species among all seven plots were the same for the two studies even though the data from the individual quadrats were often different because the exact locations of the quadrats were not available from the study.



FIGURE 15. Marginal woodfern (*Dryopteris marginalis*), a species noted by Wagner (1979) as common at Warren Dunes State Park and rare in other areas of southern Michigan as photographed in 2004.

The most commonly encountered tree species in the northern part of WDSP (Mount Edward area), based on these two surveys were *Acer saccharum*, *Fagus grandifolia*, *Quercus rubra*, *Tilia americana*, and *Tsuga canadensis*. The calculated average basal areas were higher for the 2005 study, which would be an expected outcome in a maturing forest over the 26 year period between the two surveys.

There were two notable differences between the 1979 and 2005 quadrat study results. The absence of *Ostrya virginiana* in the 1979 study was one of the differences. This is interesting because this species was encountered in 43% of the quadrats in 2005. Although *Ostrya virginiana* was noted as an understory species in 1979 (which indicated that no specimen with a diameter at breast height of 4 cm or larger was encountered), the absence of this species is difficult to explain, especially since a heading was provided for this taxon in the data table provided by Wells and Thompson (1979) but no data appeared in the column. In addition, many individuals of this species encountered in 2005 were significantly larger than 4 cm DBH, suggesting these trees were present and large enough to be included at the time of Wells and Thompson's surveys. The other difference between the two studies was the presence of *Betula alleghaniensis* as a dominant in quadrat B-2, while it was not found at all in 2005 (quadrat 2). The

information provided for quadrat B-2 (the virgin forest area) led to the conclusion that *Betula alleghaniensis*, which accounted for 29% of the coverage of the quadrat, was an important species in this valley. It was later determined that this species had not disappeared from the valley, but rather that a very large specimen of *B. alleghaniensis* was included in the 1979 quadrat. This was an unusually large and mature specimen of *B. alleghaniensis*, and was one of only two located in the entire valley (and potentially in the entire park). The basal area of this tree alone accounted for total coverage of the plot. Since this was the only tree in the area, this plot was not representative of the valley and demonstrated a drawback to using a single 20 by 20 m (non-random) quadrat in the complex dune forests to define a local area. This result led to using an alternate method which had been used by researchers in the nearby Warren Woods forest. The point-centered quarter method was selected to survey the park forests because transects could be used to cross the terrain from east to west. The method was simple to apply, was sample intensive, required less field time and was considered to be the most efficient of the available distance methods (Mueller-Dombois & Ellenburg 1974). A noted drawback of the point-centered quarter method is that the less common tree species may be overlooked. However, since part of this study also included a plant inventory (Smith & Woodland 2006), the less common trees were included in that study for WDSP.

*Quercus rubra* and *Acer saccharum* ranked consistently among the top two species in frequency, dominance and distribution for all eight transects. As previously discussed, importance values (I.V.'s) are calculated using information on the average distances between trees, size of the trees, and the number of the trees encountered (relative frequency, relative dominance, and relative density). A graph of the I.V. data for the top 5 ranked species is given in Figure 16, which clearly shows that *Q. rubra* and *A. saccharum* are the most important species across all transects. Therefore, although WDSP has a very diverse patchwork of forest communities as noted by Kost et al. (2002), Wells & Thompson (1979, 1982) and also our quadrat analyses in 2005, our transect data show it to have a more or less uniform *Quercus rubra*-*Acer saccharum* dominated forest community.

A forest composition study conducted by Donnelly and Murphy (1987), utilized the point-centered quarter method to determine the forest composition of Warren Woods, a nearby state park, located inland within five miles of WDSP. Their study showed *Fagus grandifolia* and *Acer saccharum* had the highest importance values (150.6 and 108.0, respectively). Warren Woods is considered to be a rare remnant of presettlement days (Donnelly & Murphy 1987) and one of the few virgin hardwood forests remaining in Michigan (Anonymous 2005b). A summary of the forest composition of Michigan forests based on estimates of the presettlement cover was also conducted by Donnelly and Murphy (1987) and as the authors expected, showed similar I.V.'s to those of Warren Woods. *Quercus rubra* was not listed for the Warren Woods area and had an I.V. of only 0.9 for the presettlement forests (Donnelly & Murphy 1987), demonstrating an important difference between the forests that developed on the dunes adjacent to Lake Michigan and those that developed further inland.

Why is *Q. rubra* such an important species of the forested dunes at WDSP,



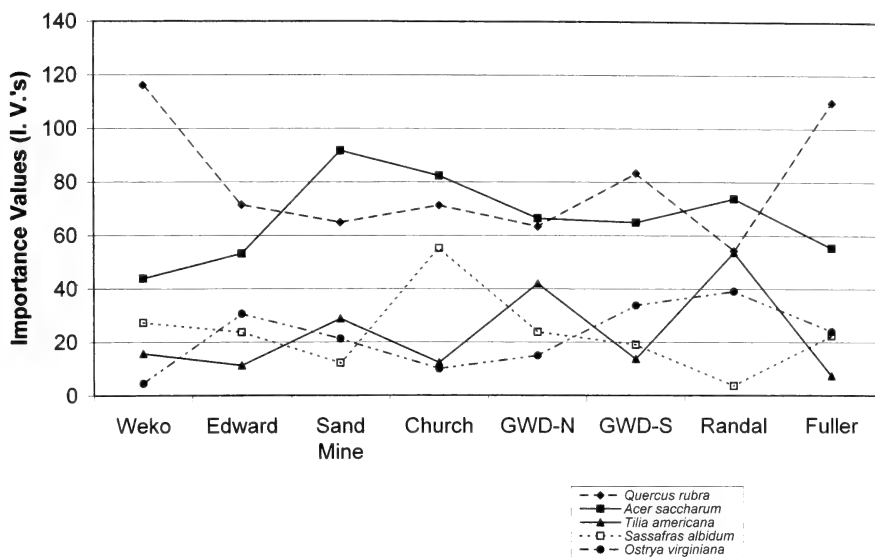


FIGURE 16. Importance Values (I.V.'s) calculated for the five highest ranked species using data from the dune forest transect survey conducted at Warren Dunes State Park, Berrien County, Michigan, September–October, 2005.

whereas this is not the case at Indiana Dunes National Lakeshore which lies just to the south (Greenburg 2002) and Warren Woods, which lies less than five miles away? First of all, as noted by Barnes and Wagner (2003), unlike other species of oaks that often represent a late successional stage, *Q. rubra* is considered a middle stage successional species. The dune areas are the youngest areas geologically speaking, and intermediate successional stage species would be expected. In addition, *Q. rubra* inhabits the most mesic habitats of all the Chicago Region oaks according to Swink & Wilhelm (1994), who define the Chicago Region as a 22 county area surrounding the south end of Lake Michigan. The characteristic topography of the dunes in Berrien County resulted in a vegetation cover much different from the nearby dune areas located to the south in Indiana and Illinois. The Berrien County dunes are steeper and more mesic in nature than other nearby dune areas according to Greenberg (2002). Because of the location of these dunes on the east rather than the south side of Lake Michigan, there is a longer growing season, more precipitation and less fire than the regions that lie just to the south. This is due to the prevailing southwesterly wind direction. The prevailing winds have also sculpted the Berrien County dune landscape in such a way that dune ridges are largely oriented parallel to the Lake Michigan shoreline. The sustained wind speeds typical for this area are the forces that allow the dunes to reach heights over 60 m (Greenberg 2002). Indiana Dunes National Lakeshore, which lies on the south end of Lake Michigan, does not have a landscape that consists of the high dunes and forested dune ridges so characteristic of WDSP (Greenburg 2002). Fire played a significant role in the development of

the plant communities at Indiana Dunes and not those in the WDSP area of Michigan (Greenburg 2002). Many oaks are considered fire adapted species, but *Q. rubra* is not, and compared to many other oaks, it is more shade tolerant (Barnes & Wagner 2003). It is thus understandable why *Q. rubra* was found to be a dominant species at WDSP.

*Acer saccharum* was another important species of the forested dunes. This was the expected dominant of the mesic old growth and presettlement woods of Berrien County, as mentioned previously. Therefore, it is not unexpected to find it as a dominant of the mesic woods of WDSP. Many of the other forested dune species listed by Donnelly and Murphy (1987) and Kost et al. (2002) included species noted from the 2005 transect survey: *Acer rubrum*, *Carpinus caroliniana*, *Carya cordiformis*, *Cornus florida*, *Fraxinus americana*, *Juglans cinerea*, *Liriodendron tulipifera*, *Ostrya virginiana*, *Populus deltoides*, *Prunus serotina*, *Quercus alba*, *Q. muhlenbergii*, *Q. velutina*, *Ulmus americana*, *Tilia americana*, and *Tsuga canadensis*.

Interestingly, *Pinus strobus* was not listed in either of the forest analyses conducted by Donnelly and Murphy (1987). Swink and Wilhelm (1994, p. 572) state that "At one time it [*Pinus strobus*] was very common in the dune country in Lake, Porter, LaPorte, and Berrien Counties." They also noted *P. strobus* was still an important component of the forested dunes in Berrien County. In this study, the I.V.'s for *P. strobus* ranged from 2.4–23.3 among the five transects where this species was recorded. This species was encountered on the western dunes and the eastern lowlands of the park, where it was often associated with *Tsuga canadensis* on north-facing slopes. At WDSP, *T. canadensis* was most common on north-facing slopes and in the steep ravines that occur between old dune ridges. Small areas with solid stands of *T. canadensis*, which are noted as being uncommon by Barnes and Wagner (2003), occur in areas of the park. One of these unique areas was noted in the Mount Edward tract that Wells and Thompson (1979) refer to as the "Hemlock Pond" (Figure 8).

The information collected on the forest structure, which include the estimated average distance between trees and the average basal areas, are both indicative of mature and potentially old growth stands. Average distances between trees ranged from 3.5 to almost 5 meters. The basal area data further demonstrate that a large number of trees would be considered large and mature specimens, with some trees reaching 108 cm DBH. The approximate average DBH for all the trees measured during the transect analyses is 25 cm. The DBH range for individual trees range from 4–108 cm DBH. Individual transect averages ranged between 20–30 cm DBH.

The quadrat analyses and other researchers' studies demonstrated that there is a diverse patchwork of at least three different communities that make up the forested dune areas at WDSP. The transect study of the forested dune area revealed a surprisingly uniform forest composition, with *Quercus rubra* and *Acer saccharum* the most important tree species dominating the forested dune area at WDSP. Comparing results to similar studies conducted previously, either in the park or nearby, demonstrated that the forests of WDSP are different than other forested areas, suggesting the uniqueness of this forest. Several species of plants including *Dryopteris marginalis*, *Vitis aestivalis*, and *Pinus strobus*, as well as a



number of rare plant species including *Morus rubra* and *Panax quinquefolius*, further demonstrate the unique character of this forest compared to nearby woodlands. Certainly, the location of the park, the proximity to a Great Lake and the resulting unique climatic regimes with more precipitation, moderated temperatures, longer growing seasons and the topography, contribute to the unique vegetation. In addition, the effects of wind and fire in the ecology of the dune community at WDSP also contribute to the uniqueness of this dune forest. This study and others conducted at WDSP indicate the forests were relatively minimally harvested for timber since the turn of the century, compared to other nearby areas, and that some sections of virgin forest exist. This adds a significant component to the ecological value of this park.

Notable imminent threats to the biodiversity of the forests at WDSP exist. The presence of the emerald ash borer will likely cause ash trees to disappear from the forested dunes at WDSP. The deer population which continues to remain at excessive levels in southwest Michigan, will likely cause the extirpation of some vascular plant species at WDSP. Kost et. al. (2002) posit that *Taxus canadensis* will likely become extirpated in the near future at WDSP due to the deer population. A number of herbaceous species encountered in 1979 appear to have disappeared as well: *Coptis groenlandica*, *Goodyera pubescens*, and *Chimaphila umbellata*. There are several state-listed threatened plant species that occur specifically in the forested dune areas at WDSP, one of which (*Panax quinquefolius*) is currently being over-harvested by humans at WDSP and whose population appears to be declining at the park; this species could also become extirpated in the near future.

It is the hope of the authors that this study will provide good baseline information on the forest composition of the forested dune area at WDSP and that this work helps to demonstrate the significant value and unique character of this land to the people of the State of Michigan, and the immediate need for it's continued and hopefully more diligent protection in the future from a variety of threats.

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**AUTHORSHIP OF THE NAME  
*CENTAURIUM PULCHELLUM* (GENTIANACEAE)**

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ABSTRACT

Valid publication of the combination *Centaurium pulchellum* should be attributed to (Swartz) Hayek ex Handel-Mazzetti et al.

KEY WORDS: *Centaurium*, Gentianaceae, nomenclature

*Centaurium pulchellum*, the lesser or branching centaury, is native to Eurasia and widely naturalized elsewhere. In North America, where it has been known as a naturalized species for about two centuries, most of its populations are in the East and the Great Lakes region, with isolated occurrences south to the Gulf Coastal region and west to California and Washington. In Michigan, especially, it has increased conspicuously in recent years.

Authorship of the binomial *Centaurium pulchellum* is usually attributed to “(Sw.) Druce, Fl. Berks. 342. 1897.” As noted in *The International Plant Names Index* (<http://www.ipni.org/index.html>; accessioned 5 Jun 2007), however, in *The Flora of Berkshire* (1898) Druce published this combination only as a provisional name that would become appropriate if the genus name *Centaurium* Hill should be adopted. At that time Druce accepted *Erythraea*, with its authorship attributed to Richard, as the correct name for the genus, and *E. pulchella* (Swartz) E. M. Fries as the correct name for the species, *Gentiana pulchella* Swartz being the basionym. In some references the combination *C. pulchellum* is attributed to “(Sw.) Druce, Fl. Oxf. 342. 1897,” but this is simply an error for “Fl. Berks.” In *The Flora of Oxfordshire*, ed. 1 (Druce 1886), *Erythraea* is the accepted name for the genus. Druce was aware of Hill’s (1756–1757) *The British Herbal*, in which Hill had published the generic name *Centaurium*, and he later advocated the acceptance of generic names of pre-Linnaean origin as having been validly published in that work. As of 1898, however, this was a matter of controversy, because Hill had not adhered to the binomial format for the names of species (Barnhart 1899; Stearn 1967). Druce did use the name *Centaurium pulchellum* in later publications, after the generic name *Centaurium* had become widely accepted, but in the interim other works pertinent to this topic were published.

A few recent authors, mostly European, have attributed the combination *C. pulchellum* to E. H. L. Krause, but Krause (1903) likewise published it only as a provisional name. His treatment of the genus is headed: **Tausendgüldenkräuter**, *Erythraea*. The generic name *Centaurium* is mentioned only in the text,

as a synonym. His wording for the species is: Kleines Tausendgüldenkräuter, *Erythraea pulchella* oder *Centaureum pulchellum* [fonts as in original]. No authorship was cited for the provisional name.

One other attribution of the authorship is listed in *The International Plant Names Index*, to “Hayek, Oesterr. Bot. Z. 56: 70. 1906,” but that is not entirely correct either. In that publication, Handel-Mazzetti et al. (1906) accepted the binomial *Centaureum pulchellum* (as *Centaureum*, an orthographic variant) which they attributed to “(Sw.) Hayek in litt.” They did not cite any publication by Hayek in this context, nor did they indicate that Hayek participated in the authorship of the work in which the combination was published.

A search for early works in which the generic name *Centaureum* (or *Centaureum*) had been accepted disclosed none earlier in which the name *C. pulchellum* was accepted. Therefore, in accord with Articles 46.4 and 46.7, Ex. 36, and Recommendation 46C.2 of the *International Code of Botanical Nomenclature* (McNeill et al. 2006), authorship and valid publication of the combination *Centaureum pulchellum* should be attributed to (Swartz) Hayek ex Handel-Mazzetti et al., Oesterr. Bot. Z. 56: 70. 1906.

#### ACKNOWLEDGMENTS

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On the cover: *Stabilized forested dunes near Lake Michigan meet the edge of the active sand dunes at the Great Warren Dune area of Warren Dunes State Park, Michigan.*  
*Photo May 31, 2005, by Pam Smith.*

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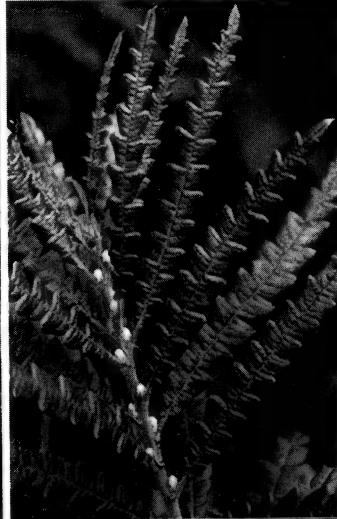
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## CHANGES IN HOOSIER PRAIRIE OAK SAVANNA DURING 27 YEARS OF PRESCRIBED FIRE MANAGEMENT

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### ABSTRACT

Hoosier Prairie Nature Preserve, located in northwestern Indiana, protects a rare and unusually high quality example of a Midwestern (USA) oak savanna. Although many savannas in the region have been lost to agriculture, urbanization, and fire suppression, parts of the 178 hectare preserve never lost its historic community structure. A program of prescribed burning was initiated in 1978 and monitoring of two  $10 \times 10$  m sample areas (Blocks) began in 1979. Throughout the 27 year observation period each Block retained a distinct understory composition even though subjected to similar fire regimes. At the same time, each underwent notable and individualistic changes from their original species composition (SSI = 64–69%) but continued to support a remarkably high diversity of xeric and mesic forbs. Native species richness ranged from 34–58 species per Block and as high as 16.8 species per  $0.67 \text{ m}^2$  quadrat. Additionally, according to the Floristic Assessment metrics, the species quality of contemporary Hoosier Prairie is comparable (mean C = 4.9) to that expected in regional pre-settlement oak savanna communities.

**KEYWORDS:** savanna, fire management, succession, species composition, floristic quality

### INTRODUCTION

In the pre-settlement Midwestern United States, oak savanna formed a transition zone between the eastern deciduous forest and tall grass prairie biomes (Nuzzo 1986). Although definitions of Midwestern oak savanna vary (Nuzzo 1986; Heikens and Robertson 1994), these savannas are generally described by their physiognomy: a community characterized by scattered, open-grown, somewhat even age trees that mostly belong to the genus *Quercus* (Curtis 1959). This leaves open the question of how much canopy cover may be associated with the savanna community. Curtis (1959), working in Wisconsin, suggested a range of at least one tree per acre but less than 50% canopy cover, boundaries affirmed by Anderson and Bowles (1999). In contrast, D.M. Anderson (1982), in classifying

vegetation communities for Ohio, placed more emphasis on the prairie-like nature of the savanna understory. As a result his definition of oak savanna encompasses a canopy cover from 10 to near 100 per cent (Anderson 1982).

Regardless of the precise definition or range of canopy cover, the open canopy structure and prairie-like understory of Midwest savannas are a result of periodic drought and fires (Anderson and Bowles 1999). During the pre-settlement period and through the 19<sup>th</sup> century, the frequency of fire in Midwestern savannas was remarkably high. Guyette and Cutter (1991), for example, estimated that the fire-free interval was only 4.3 years in their study of Ozark post oak savanna. With fire suppression during the 20<sup>th</sup> century (Taylor 1990), many savannas converted into closed forest as woody cover from oak sprouts and grubs increased (Cottam 1949, Anderson and Brown 1983, Robertson and Heikens 1994) and more shade tolerant and fire intolerant species invaded (Anderson and Schwegman 1991; McClain et al. 1993). The conversion to closed woodland was particularly rapid in deep-soil savannas, a community type now completely lost from the upper Midwest region (Leach and Ross 1995).

Hoosier Prairie Nature Preserve, a part of the Indiana Nature Preserve system since 1977, includes a dry-mesic sand savanna (Bacone 1977) with widely spaced black oak trees (*Quercus velutina* Lam.). Given its location in northwestern Indiana one would consider Hoosier Prairie to be part of the so-called prairie peninsula (Transeau 1935). Because of its proximity to Lake Michigan, it should be noted that the site was lake bottom during a portion of the post-Wisconsinan glacial period. Thus, topographic relief is minimal and the vegetational history of the site is relatively short at approximately 8000 years or less (Hartke et al. 1975). Because of this combination of factors, Hoosier Prairie may represent a particularly uncommon type of remnant oak savanna.

At the time of purchase and its designation as an Indiana state nature preserve, portions of Hoosier Prairie retained a high quality prairie understory while other degraded sections had dense woody understory (Bacone 1977). Although the use of prescribed fires was an unfamiliar and even controversial management tool for nature preserves in Indiana at the time, immediate fire management was recommended (Bacone 1977). In the intervening period, a more substantial literature regarding the benefits and community dynamics in response to fire has developed. These studies have demonstrated that fire increases cover of prairie herbaceous species (e.g., Tester 1989; Abella et al. 2004) especially after a program of multiple prescribed burns (King 2000; Heikens et al. 1994). Although a 2-year burn cycle may produce the highest species richness (Tester 1989), the effects of prescribed burn are also dependent upon the season of the year and fuel load. Dornbush (2004) reported a shift from xeric toward more mesic and late flowering species when burns were limited to spring and Howe (1994, 1995) observed an increase in C<sub>3</sub> over C<sub>4</sub> species following cycles of mid-summer fire. In terms of fuel load, biomass accumulation between burns needs to be sufficient to achieve the anticipated reduction in sapling and shrub cover (Anderson and Brown 1986; Rebertus and Burns 1997). A thirteen year program of annual burning (White 1983), while successful in increasing the herbaceous species richness, failed to return tree density to historic savanna condition due to low mortality in individuals exceeding 25 cm dbh. In fact, once a site has lost its historic com-

munity structure due to fire suppression, its restoration can prove to be slow and uneven (Anderson et al. 2000; Abella et al. 2004).

At Hoosier Prairie, a prescribed burn program was initiated in winter of 1978 that sought to simulate a presettlement fire regime. The adopted regimen recognized that regional Amerindians used frequent dormant season burns to drive game, improve pasture, and increase yields of food plants (Anderson 1990). At the same time, it ignored the possible role of less frequent summer fires set by dry lightning (Howe 1994,1995; Loope and Anderson 1998), in part because their potential importance was unknown at the time. Over the past 27 years, as many as 13 burns were administered on some sections of Hoosier Prairie Nature Preserve. The program included late fall as well as spring burns at intervals that ranged from seven to 72 months apart. In 1978 and 1979, plots were established with the intent of following the long term changes at Hoosier Prairie and monitoring the effects of the fire management program. The objective of this paper is to report the changes observed over the past 27 years in understory vegetation including fluctuations in species composition and floristic quality.

## METHODS

### *Site Description*

Hoosier Prairie is a 178 hectare site located on the west side of the town of Griffith in Lake County, Indiana (Figure 1). The property is bounded on the west by Kennedy Avenue and more or less bisected by the east-west road, Main Street. The topography has only minor relief of less than 2 m. As a result, small changes in elevation result in rapid transitions from the xeric savanna into wet prairies and marshes. The soils of xeric areas are porous Brems fine sand, Watseka loamy fine sand, and Maumee Loamy fine sand (NRCS 2006).

### *Data Collection and Analysis*

In 1978 and 1979, 2 permanent plots were established, one south of Main Street (designated South Block; N 41.52171° / W 87.45315°) and the other to the north of road (North Block; N 41.52361° / W 87.45435°), separated by a distance of approximately 225 m. These Blocks were randomly placed within areas deemed as having the highest quality oak savanna condition. Each 10 x 10 m plot consisted of 25 contiguous sample areas of 2 x 2 m. Within each sample area the species present were recorded from a 0.67 m<sup>2</sup> area demarked by the more or less blind toss of a circular hoop. Nomenclature for species follows Swink and Wilhelm (1994); vouchers for Hoosier Prairie are available at MOR. In the South Block the first sampling was attempted in September 1978 but the data set is incomplete. Thus, these data provide some useful qualitative information about the site before fire management but could not be used in quantitative analyses. Full data collection on both Blocks began in 1979, the year following the first prescribed burns, and was performed annually from 1979 to 1994 during late July / early August. Two additional samplings were completed in early August 2004 and 2006. No data are available for the North Block in 1980. In the South Block, prescribed burns were administered during the spring of 1984, 1985, 1987, 1988, 1990, 1992, 1994, 1997, 2000, 2006 and early winter of 1978, 1979, and 1982. The North Block was burned during the spring of 1978, 1984, 1988, 1990, and 1998 and early winter of 1979, 1981, 1985, 1990, 1993, and 2001.

Changes in community structure were examined by Nonmetric Multidimensional Scaling (NMS) using PC-ORD5 software (McCune and Mefford 2006). Sørensen (Bray-Curtis) served as the distance measure. A random starting configuration was employed in the first run of 50 real data and 50 randomized data iterations. Scree plots recommended that two dimensions be analyzed in the final runs. The final runs had 200 iterations and in each case an  $r^2$  greater than 0.84. The resulting Kruskal stress was very low (<1) for the combined Block analysis and low (7.5) to moderate (14.3) for the South and North Blocks respectively. To further quantify the degree of community change over time

**Hoosier Prairie Nature Preserve  
Lake County**



FIGURE 1. Site map of Hoosier Prairie Nature Preserve, Lake County, Indiana. Note its proximity to the town of Griffith and land dominated by industrial activity.

Sørensen's Similarity Indices (SSI) were calculated for each Block with 1979 as the base year. In order to assess whether the management program affected any long term changes in the floristic quality on the site, several metrics used in Floristic Quality Assessment (FQA; Swink and Wilhelm 1994) were applied. FQA draws upon the concept of conservatism, an estimation of the fidelity of any particular plant species to an undisturbed, pre-settlement community such as an oak savanna. Each species in the Chicago region has an assigned coefficient of conservatism (Swink and Wilhelm 1994) where C ranges from 0 for ruderal species to 10 for species limited to communities with little human disturbance. Based upon the species observed and their richness (n), mean coefficients of conservatism (mean C) and floristic quality indices (FQI) can be calculated, where  $FQI = \text{mean } C \sqrt{n}$ . In this study, we calculated these metrics at both an overall Block level as well as at the quadrat level. FQA metrics generally are calculated both with and without non-native species in order to evaluate the impact of non-native species upon community structure. In these sites non-native species were few and of low frequency and, therefore, only FQA metrics for native species are reported.

## RESULTS

### *Changes in Community Composition*

According to NMS, the understories of the North and South Block throughout the observation period were markedly different from each other (Figure 2A). The North Block (Figure 3) is dominated by the herbs *Carex pensylvanica*, *Pteridium aquilinum*, *Helianthus divaricatus*, *Maianthemum canadense*, *Potentilla simplex*, and *Arenaria lateriflora* (Table 1). Dominant shrubs include *Vaccinium angustifolium* and *Rosa carolina*. Other characteristic species include *Amphicarpaea bracteata*, *Rubus flagellaris*, *Rhus glabra*, and *Anemone quinquefolia*. The South Block (Figure 4), on the other hand, has a higher frequency of shrubs including *Vaccinium angustifolium* and *Comptonia perigrina* and a high frequency of the herbs *Carex pensylvanica*, *Comandra umbellata*, *Parthenium integrifolium* and *Potentilla simplex* (Table 1). Other species prevalent in the South Block include *Helianthus mollis*, *Aster dumosus*, and *Andropogon scoparius*. Although *A. scoparius* and seven additional native grass species were observed within the sample plots, none were dominant species.

The strong inter-Block differences in species composition (Figure 2A) were maintained throughout the 27 year observation period and had a much greater magnitude than within-Block changes (Figure 2B–C). As a result, the overall NMS plot of Figure 2A is not able to depict fine grained, year to year intra-Block changes. Nonetheless there were important underlying changes in community composition at the Block level. One measure of change, namely similarity (SSI) based upon the presence or absence of individual species, indicates that the amount of change was almost equivalent within each Block (Table 2): in 2006, the North Block had an SSI = 64% and the South Block an SSI = 69% when compared to the base year of 1979.

NMS (Figure 2B–C) and SSI (Table 2) of each Block alone revealed more specific historical change. During the first three years of observation (1979–1981), both Blocks exhibited a directional change (Figure 2B–C). This directionality was also evident in coefficients of similarity (Table 2), especially for the South Block. Over the period of 1981–1983, the South Block quickly fell to the range of SSI = 68–77% while the North Block declined to an SSI = 83–89%. The stronger changes in the South Block can primarily be attributed to a decline

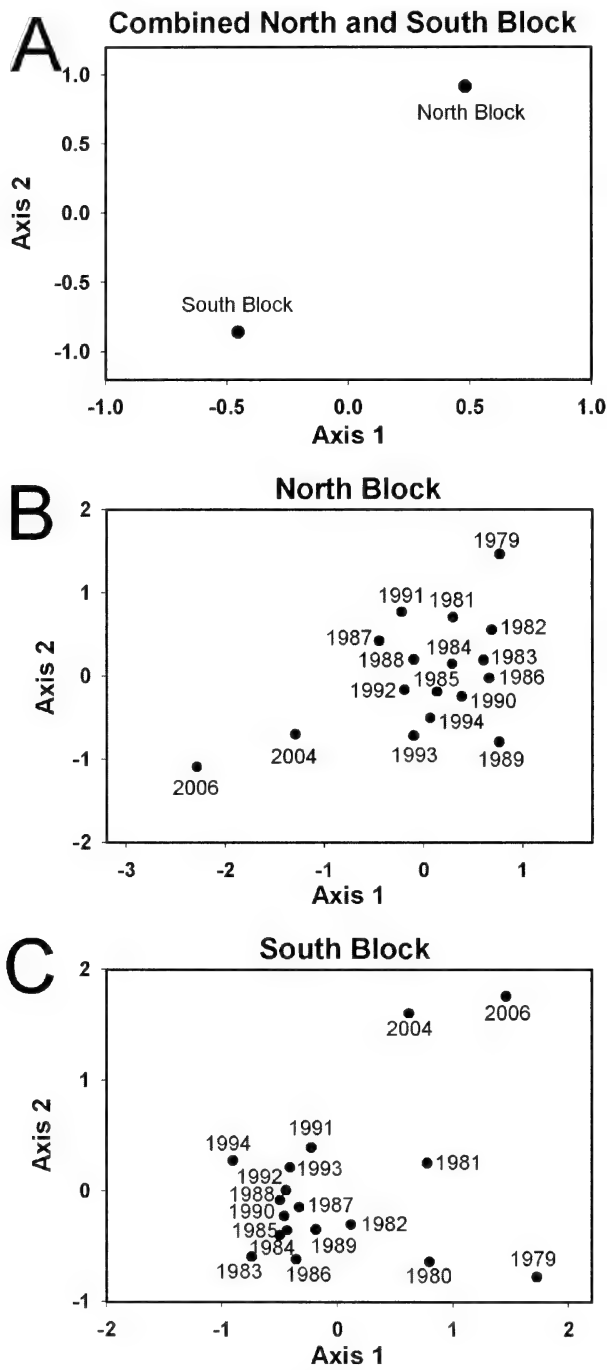


FIGURE 2. Nonmetric Multidimensional Scaling for two observation Blocks at Hoosier Prairie, 1979–2006. A. Combined data for the North and South Block. B. Analysis for North Block alone. C. Analysis for South Block alone.



FIGURE 3. View of the North Block in August, 2006.

in the frequency of the old field species *Solidago altissima* (from 44 to 0%) and the shrub *Gaylussacia baccata* (from over 50% to mostly less than 20%) and an increase in that of *Carex pensylvanica* (from 50 to over 80%). In addition, several species, including *Aster azureus*, *Krigia biflora*, and *Panicum virgatum*, were not observed within the South Block until 1981–1982. From the period of 1981 to 1994 further changes in the community composition of the two Blocks lacked any obvious pattern. On the other hand, the most recent sample dates, 2004 and 2006, detected a shift in composition. In the South Block several grass species, *Andropogon gerardii* and *Sorghastrum nutans*, as well as several forbs declined in frequency, while during this same period the frequency of *Panicum implicatum*, *Aster umbellatus*, *Cuscuta coryli*, and the annual *Erechtites hieracifolium* increased. On the North Block during the period from 1994 to 2006, there was an increase in the frequency of *Desmodium glutinosum* (from 12 to 76%) as well as *Quercus velutina* saplings (from 36 to 68%) and *Comptonia peregrina* (from 32 to 52%). By 2004 *Panicum virgatum* and *Tradescantia ohiensis*, which in some years before 1994 were present in more than half of the quadrats, were completely absent. *Pteridium aquilinum* and *Helianthus divaricatus* also exhibited meaningful decreases in frequency.

### ***Floristic Quality Assessment***

Based upon the concepts of conservatism and species richness, FQA can provide insight into whether there are changes in community quality through time. Overall the richness of native species (Figure 5A) in the South Block ranged from 41 to 58 species. This was, on average, higher than that observed in the

TABLE 1. List of the 60 most common understory species in two 10 × 10 m blocks at Hoosier Prairie Nature Preserve: species, mean frequency, and frequency range (over the period 1979–2006). The North Block had a total of 75 species and the South Block had 96 species.

NORTH BLOCK			SOUTH BLOCK		
Species	Mean Frequency	Frequency Range (1979– 2006)	Species	Mean Frequency	Frequency Range (1979– 2006)
<i>Carex pensylvanica</i>	98.4%	88–100%	<i>Vaccinium angustifolium</i>	85.8%	60–96%
<i>Pteridium aquilinum</i>	88.5	56–100	<i>Comptonia peregrina</i>	81.3	60–96
<i>Helianthus divaricatus</i>	86.4	60–96	<i>Carex pensylvanica</i>	81.0	64–92
<i>Maianthemum canadense</i>	78.7	56–96	<i>Comandra umbellata</i>	67.3	12–96
<i>Vaccinium angustifolium</i>	76.0	52–92	<i>Parthenium integrifolium</i>	64.5	48–84
<i>Rosa carolina</i>	74.4	64–92	<i>Potentilla simplex</i>	64.3	36–80
<i>Potentilla simplex</i>	66.1	44–80	<i>Tradescantia ohiensis</i>	57.8	4–72
<i>Arenaria lateriflora</i>	65.3	0–88	<i>Rubus setosus</i>	55.8	16–68
<i>Smilacina racemosa</i>	55.2	24–80	<i>Pteridium aquilinum</i>	50.5	28–72
<i>Rubus flagellaris</i>	53.9	4–88	<i>Salix humilis</i>	45.8	12–72
<i>Solidago juncea</i>	48.3	12–92	<i>Solidago juncea</i>	45.5	4–72
<i>Tradescantia ohiensis</i>	39.5	0–60	<i>Rubus hispidus</i>	42.5	32–60
<i>Rhus glabra</i>	36.8	4–56	<i>Helianthus mollis</i>	36.8	4–68
<i>Amphicarpaea bracteata</i>	35.2	12–68	<i>Aster umbellatus</i>	35.3	0–64
<i>Anemone quinquefolia</i>	32.0	4–56	<i>Fragaria virginiana</i>	34.3	4–56
<i>Coreopsis tripteris</i>	28.8	12–48	<i>Andropogon scoparius</i>	31.0	0–76
<i>Coreopsis palmata</i>	25.9	20–32	<i>Sorghastrum nutans</i>	28.3	8–60
<i>Comptonia peregrina</i>	24.0	4–52	<i>Aronia prunifolia</i>	28.0	16–40
<i>Fragaria virginiana</i>	23.7	4–36	<i>Viola sagittata</i>	25.5	0–44
<i>Quercus velutina</i>	22.4	8–40	<i>Solidago gymnospermoides</i>	24.3	0–32
<i>Aster azureus</i>	22.1	0–36	<i>Gaylussacia baccata</i>	23.8	12–52
<i>Panicum virgatum</i>	22.1	0–64	<i>Panicum virgatum</i>	21.0	0–80
<i>Parthenium integrifolium</i>	19.7	12–28	<i>Smilacina racemosa</i>	17.8	4–28
<i>Rubus hispidus</i>	19.7	0–76	<i>Krigia biflora</i>	13.8	0–32
<i>Krigia biflora</i>	19.5	0–40	<i>Aster dumosus</i>	13.5	0–32
<i>Baptisia leucantha</i>	14.1	4–24	<i>Euphorbia corollata</i>	12.5	0–24
<i>Gaylussacia baccata</i>	11.7	4–20	<i>Dryopteris thelypteris</i>	11.3	0–20
<i>Poa pratensis</i>	11.2	0–60	<i>Lespedeza capitata</i>	11.3	0–28
<i>Viola sagittata</i>	11.2	0–48	<i>Andropogon gerardii</i>	10.8	0–80
<i>Solidago speciosa</i>	8.3	0–24	<i>Phlox pilosa</i>	10.8	0–20
<i>Salix humilis</i>	8.3	0–16	<i>Populus tremuloides</i>	10.3	0–28
<i>Desmodium canadense</i>	7.5	0–24	<i>Aster azureus</i>	10.0	0–28
<i>Euphorbia corollata</i>	7.2	0–20	<i>Coreopsis tripteris</i>	10.0	0–20
<i>Apocynum androsaemifolium</i>	6.4	0–12	<i>Spiraea tomentosa</i>	9.6	0–24
<i>Rudbeckia hirta</i>	6.1	0–24	<i>Baptisia leucantha</i>	8.5	1–20
<i>Aster umbellatus</i>	5.3	0–12	<i>Panicum villosissimum</i>	8.3	0–20
<i>Galium triflorum</i>	5.3	0–96	<i>Arenaria lateriflora</i>	8.0	0–40
<i>Andropogon gerardii</i>	4.8	0–20	<i>Quercus velutina</i>	7.8	0–16
<i>Muhlenbergia mexicana</i>	3.5	0–12	<i>Houstonia caerulea</i>	7.5	0–60
<i>Poa compressa</i>	3.2	0–20	<i>Spartina pectinata</i>	6.8	0–20
<i>Desmodium glutinosum</i>	2.9	0–76	<i>Quercus alba</i>	6.7	0–20
<i>Solidago altissima</i>	2.9	0–16	<i>Maianthemum canadense</i>	6.5	0–16
<i>Asclepias syriaca</i>	2.1	0–32	<i>Lycopus uniflorus</i>	6.0	0–12
<i>Polygonatum canaliculatum</i>	2.1	0–16	<i>Liatris spicata</i>	5.3	0–20
<i>Sorghastrum nutans</i>	2.1	0–24	<i>Solidago altissima</i>	5.3	0–44
<i>Viola fimbriatula</i>	2.1	0–20	<i>Rudbeckia hirta</i>	5.0	0–28
<i>Achillea millefolium</i>	1.9	0–4	<i>Calamagrostis canadensis</i>	4.5	0–40
<i>Cirsium discolor</i>	1.9	0–8	<i>Poa pratensis</i>	4.5	0–24



TABLE 1. (Continued).

NORTH BLOCK			SOUTH BLOCK		
Species	Mean Frequency	Frequency Range (1979– 2006)	Species	Mean Frequency	Frequency Range (1979– 2006)
<i>Liatriis aspera</i>	1.9%	0–12%	<i>Eryngium yuccifolium</i>	4.3%	0–12%
<i>Liatriis spicata</i>	1.9	0–12	<i>Lechea tenuifolia</i>	3.8	0–16
<i>Lespedeza capitata</i>	1.3	0–4	<i>Tephrosia virginiana</i>	3.8	0–8
<i>Panicum depauperatum</i>	1.3	0–4	<i>Desmodium canadense</i>	3.5	0–20
<i>Rhamnus frangula</i>	1.3	0–20	<i>Helianthus rigidus</i>	2.8	0–28
<i>Prenanthes racemosa</i>	1.1	0–4	<i>Panicum implicatum</i>	2.8	0–48
<i>Prunus serotina</i>	1.1	0–8	<i>Apocynum</i>		
<i>Comandra umbellata</i>	0.8	0–4	<i>androsaemifolium</i>	2.5	0–16
<i>Solidago graminifolia</i> var.			<i>Cuscuta coryli</i>	2.5	0–60
<i>nuttallii</i>	0.8	0–8	<i>Helianthus divaricatus</i>	2.5	0–16
<i>Sonchus uliginosus</i>	0.8	0–4	<i>Polygala sanguinea</i>	2.5	0–12
<i>Agrostis alba</i>	0.5	0–4	<i>Pycnanthemum virginianum</i>	2.5	0–8
<i>Andropogon scoparius</i>	0.5	0–4	<i>Salix petiolaris</i>	2.3	0–16

North Block (which ranged from 34 to 48 species per sample date). During the observation period, according to regression analysis, the richness of native species increased ( $r^2 = 0.63$ ,  $p = 0.0001$ ). The South Block, by contrast, had more variation in species richness ( $r^2 = 0.15$ ,  $p = 0.12$ ). It experienced a slight increase in species richness through 1994, followed by an unexpected low value in 2004. However, in 2006 species richness returned to the higher levels observed in 1993–4. We attribute this fluctuation to the almost 5-year lapse time in prescribed burn (from 2000 to 2005) followed by a post-burn rejuvenation (in 2006).

Throughout the observation period the two Blocks were remarkably free of non-native species. Six species were present in the North Block and three in the South Block. The most frequent non-native species in both locations was *Poa pratensis*. During most years its frequency was well below 20% in each Block and in 2006 it was only encountered in one quadrat. A second exotic species, *Rhamnus frangula*, is the object of ongoing management to prevent invasion. In 2006 it was sighted in two quadrats within each Block. Because non-native species have a very limited presence in the monitored areas, the remaining FQA analysis results are based upon native species only.

As already described above, the overall species richness of the more shaded North Block was lower than that of the South Block. The same trend applied when species richness is analyzed at the quadrat level (Figure 5A). In peak year of 1994, the Hoosier Prairie savanna supported a mean of 15.3 (North Block) to 16.8 (South Block) species per quadrat. The years with fewest species per quadrat occurred in 1979 (North Block) and 1981 (South Block). Regression analysis suggests that quadrat-level species richness in the two Blocks has not changed meaningfully over the 27 year period.

As with species richness, mean C values (both overall as well as at the quadrat level; Figure 5B) were higher in the South Block. Over the 26 years,



FIGURE 4. View of the South Block in August, 2006.

mean C (overall) for the South Block ranged narrowly between 5.7 and 6.3. Those of the North Block ranged from 4.8 to 5.6 with the lowest mean occurring in 2004. As one would expect, FQI values for the South Block were higher than those for the North (Figure 5C). Across the two Blocks, FQI values ranged from 31 to 47 with those in the North Block increasing with time ( $r^2 = 0.31$ ,  $p = 0.02$ ).

## DISCUSSION

When dedicated as a state nature preserve in 1977, Hoosier Prairie supported a variety of savanna, prairie, and wet habitat of varying degrees of natural quality (Bacone 1977). The two Blocks used in this study were established in areas where the understory supported a diverse mosaic of xeric to mesic species. The changes in species composition were traced annually over approximately 16 years and then twice after a decade long gap. This more fine grain record is in contrast to typical long term studies of community change in prairie or savanna communities where observations years were few and widely spaced (White 1983; Bowles et al. 2003; Dornbush 2004) or where data were only collected at

TABLE 2. Sørensen's Similarity Index (SSI) within each Block for selected years compared to 1979, the first year of monitoring. The first prescribed burns occurred during spring (North Block) and winter (South Block) of 1978 and again in the winter of 1979.

Year	North Block	South Block
1981 cp. 1979	0.89	0.77
1982 cp. 1979	0.83	0.71
1983 cp. 1979	0.85	0.68
1984 cp. 1979	0.87	0.72
1985 cp. 1979	0.83	0.70
1986 cp. 1979	0.78	0.70
1988 cp. 1979	0.75	0.75
1990 cp. 1979	0.77	0.72
1992 cp. 1979	0.72	0.74
1994 cp. 1979	0.72	0.71
2004 cp. 1979	0.70	0.70
2006 cp. 1979	0.64	0.69

the terminus of the experiment (Tester 1994). One truly longitudinal study on southern Illinois barrens (Anderson et al. 2000) included ten observation years; however, during most of the study, fire was being excluded from the site.

Our comparisons on Hoosier Prairie of two Blocks indicated that each sample area had a unique community structure at the outset and that their uniqueness persisted throughout the 27 year period of fire management. The uniqueness of each Block was undoubtedly the result of both long term differences in local site history (Sousa 1984; Lesica and Cooper 1999) as well as on-going differences in microhabitat (Zedler and Loucks 1969; Beatty 1984), which can be more pronounced in oak savanna ecosystems (Leach and Givnish 1999). In terms of readily observable differences between the two Blocks, the North Block (Figure 3) was more shaded and perhaps slightly higher topographically than the South Block (Figure 4).

In addition to the strong and persistent differences between the two Blocks, we observed gradual intra-Block change over time. In the South Block, the early cycles of prescribed fire were associated with the decline of the old field species *Solidago altissima* and the shrub *Gaylussacia baccata* (Matlack et al. 1993) and the gradual appearance of several herbaceous species. The North Block, after experiencing relatively small amounts of change in community composition during the first 16 years, ended in 2006 with as much change in community composition (as measured by SSI) as the South Block. And so, not only does the Preserve harbor a diverse understory mosaic as represented by the two sample Blocks, but over time these exhibited individualistic behavior even when exposed to similar management regimes.

Although this study documents long term changes during a program of prescribed burn, it has several limitations. Pre-burn data (i.e., 1978 or earlier), that would allow tracing the initial community changes with fire, are limited or lacking. Furthermore, one might expect that factors aside from fire, including drought and herbivory (Inouye et al 1994; Ritchie and Tilman 1995; Ritchie et al. 1998), contributed to the fluctuation in community structure during our monitoring period. For example, the classic study by Weaver et al. (1940) demonstrated

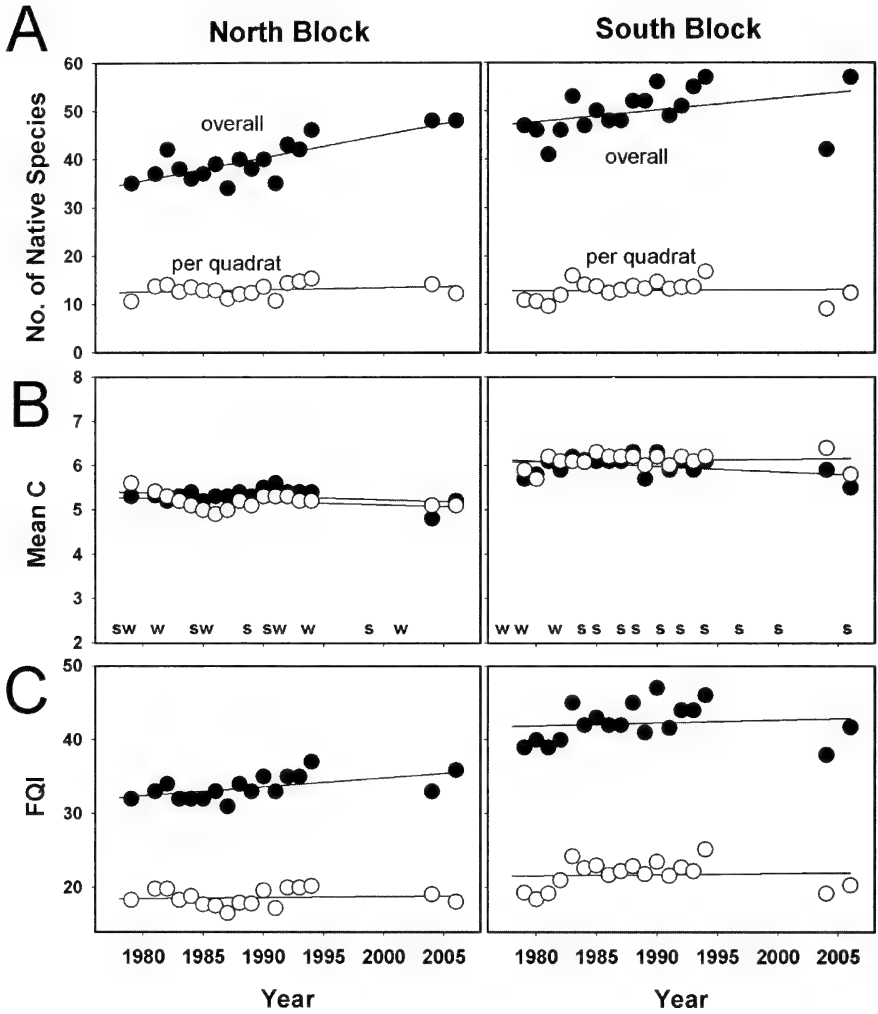


FIGURE 5. Changes in Floristic Assessment for two observation Blocks at Hoosier Prairie, 1979–2006. A. Number of native species observed. B. Mean C for native species. C. Floristic Quality Index (FQI) for native species. Closed circles are overall values for an entire Block. Open circles are per quadrat averages within each Block. Figure B indicates years with prescribed burn: w = early winter burn and s = late winter to early spring burn. No data were collected in the interval 1995–2003.

that in periods of drought there may be a differential response among guilds such as  $C_4$  grass, annuals, and  $C_3$  forbs. These fluctuations may be particularly pronounced in microsites where herbaceous vegetative must compete with mature trees for moisture (Anderson et al. 2001).

Increasingly Hoosier Prairie is an island in an urban/suburban landscape (Figure 1). In spite of this reality, it has been possible to simulate, by means of prescribed burns, one of its significant historical rhythms. The sample areas in Hoosier Prairie have continuously supported high species richness, one comparable on a quadrat basis to that reported by Leach and Givnish (1999) for Wisconsin oak savannas. In fact, as emphasized by Leach and Givnish (1999), oak savannas should be more widely recognized for their rich diversity and cover of forbs rather than grasses, an essential floristic difference from tall grass prairies that holds true for Hoosier Prairie Nature Preserve (see cover photo). During the past 27 years of fire management the sample Blocks maintained high species richness; each 100 m<sup>2</sup> Block contained in excess of 30 plant species. The North Block experienced an increase in overall species richness and, on a per quadrat basis, the richness of both Blocks usually only had small fluctuations. Of some concern, however, was the decline in 2004 of overall species richness in the South Block. We attributed this temporary decline in richness to an almost 6 year burn hiatus in this portion of the savanna (Anderson et al. 2000; Bowles et al. 2003). Unfortunately, data are not available to detail the decline over that period. However, it was clear from the 2006 sampling that the diversity had indeed returned. During 2006 our qualitative field observation was that recently burned quadrats (i.e., South Block) contained numerous seedlings, a condition not apparent in 2004. At the same time, seedlings were absent in quadrats where 4 years had lapsed since burn (i.e., North Block).

Based upon measures of mean C, fire management was successful in maintaining an assemblage of species strongly characteristic of what is considered pre-settlement condition. Each Block typically had mean C values above 5.0. These values fall at or near the expected upper limit for an undisturbed pre-settlement community (Swink and Wilhelm 1994). What will be interesting going forward is whether the Preserve can continue to achieve these remarkable quality measures in decades to come (Kellman 1996). As an island in an urban/suburban setting it does not support the historical diversity of herbivores and carnivores, it has small sized meta-populations for many plant species, and, of course, a different physical environment stemming from surrounding changes in land use (Saunders et al. 1991). As an island it is particularly dependent upon the continued cooperation of local and regional citizens to protect it against undo human disturbance and to support the on-going efforts to manage its historical oak savanna condition.

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## NOTEWORTHY COLLECTIONS

## MINNESOTA

*Allium hollandicum* Fritsch (Liliaceae, treated as Alliaceae by some). An ornamental onion.

Previous knowledge. *Allium hollandicum* is a non-rhizomatous, bulbous herbaceous perennial that most resembles the central Asian native *A. jesdianum* Boiss. and Buhse, but seems to be of European horticultural origin and was first described by Fritsch (1993). These plants, cultivated for their showy inflorescences, have sometimes been misidentified as *A. aflatunense* B. Fedtsch. (Fritsch 1993). Although the name *A. ×hollandicum* has occasionally been used in horticulture, Friesen et al. (1997) found no evidence that the popular *A. hollandicum* cultivar 'Purple Sensation' contains genomes from more than one species. McNeal and Jacobsen (2002) did not include *A. hollandicum* among the alien species escaped in North America; it has escaped from cultivation in Germany, but has not become naturalized there (Reinhard Fritsch, personal communication).

Significance. A population of *A. hollandicum* in Duluth, Minnesota seems to be the first to be reported growing outside of cultivation in North America. It was found at a sunny site within a dense growth of taller herbaceous perennials such as *Alopecurus pratensis* L., *Bromus inermis* Leysser, and *Tanacetum vulgare* L. on well-drained medium-textured soil. The onion plants developed early, and their leaves withered before the other species overgrew them enough to produce considerable shading. Abundant seed production was observed. There were eight plants in flower in 2001, 14 in 2005, and 26 in 2006, despite some being removed for specimens over this interval, as well as others that did not flower. Spatial spreading of this colony has been limited to within a few m<sup>2</sup>. Many plants were pulled out by an unknown person after the count was made in 2006. The population is in a residential neighborhood, but does not border cultivated ground.

Diagnostic characters. Among tall onions with violet anthers, deep purple perianths in fairly large and dense umbels, and strap-shaped basal leaves, *A. hollandicum* may be distinguished by the combination of equal-length pedicels and typically only two ovules per locule. Frequently just one of these two ovules matures as a seed. The dimensions given by Fritsch (1993) are from cultivated material, and plants grown with sparser resources may be less robust (Reinhard Fritsch, personal communication). The Duluth plants had smaller measurements than those of the type (Fritsch 1993), except for height, and thus trend toward *A. jesdianum* dimensionally.

Specimen citations. Minnesota. St. Louis Co.: E side of Brainerd Ave. below Lyons St., Duluth, SE¼ NE¼ Sec. 15, T50N R14W, (all this location), in flower, 3 Jun 2001, *Schimpf 305* (DUL); in flower, 13 Jun 2004, *Schimpf 356* (DUL); in



flower, 10 Jun 2005, *Schimpf* 395 (DUL); in fruit, 21 Jun 2005, *Schimpf* 404 (DUL, MIN).

*Centaurea phrygia* L. (Asteraceae). Wig Knapweed.

Previous knowledge. *Centaurea phrygia* is a herbaceous perennial that is native to Europe and established as a weed in the east-central United States (Keil and Ochsmann 2006).

Significance. Populations of *C. phrygia* from two locations in rural northeastern Minnesota are apparently the first known from the upper Great Lakes region. Both were growing with *C. ×moncktonii* Britton, which was much more abundant. Keil and Ochsmann (2006) noted that some individuals that are determined as *C. phrygia* may represent extreme variants within the *C. jacea* L. complex, which includes *C. ×moncktonii*. Both of the *C. phrygia* populations produced abundant seed. The roadside population was subjected to control actions after these collections were made.

Specimen citations. Minnesota. St. Louis Co.: occasional across a few ha of inactive hayfield on fine-textured soil, Angora Township, NE¼ SE¼ Sec. 8, T61N R18W, in fruit, 11 Sep 2005, *Schimpf* 424 (DUL, MIN), 1 Oct 2005, *Pomroy*, *Schimpf and Barnes* 2368 (DUL, MIN); same location, in flower, 15 Jul 2006, *Pomroy*, *Schimpf and Barnes* 2420 (DUL, MIN); uncommon in narrow strip on both sides of highway 73, Linden Grove Township, NW¼ Sec. 2, T62N R20W, in fruit, 11 Sep 2005, *Schimpf* 425 (DUL, MIN), 1 Oct 2005, *Pomroy*, *Schimpf and Barnes* 2369, 2370 (DUL, MIN).

*Verbena officinalis* L. (Verbenaceae). European Vervain.

Previous knowledge. *Verbena officinalis* is an annual that is native to Europe; introduced to North America as a medicinal herb, it is naturalized in southeastern and Atlantic coastal states (Gleason and Cronquist 1991). It has also been reported from western states (USDA 2006). It was collected in the 1890s in Detroit, Michigan, but not known from that state since then (Voss 1996). Although USDA (2006) indicated that it is known outside of cultivation in Wisconsin, the Wisconsin State Herbarium did not report it from the state (Wisflora 2006). Scoggan (1979) did not include it in the flora of Canada.

Significance. A population of *V. officinalis* in rural northeastern Minnesota appears to be the first known outside of cultivation in Minnesota, and perhaps also in the upper Great Lakes region. The site is a rock garden for flowers, with sandy soil. This species, never deliberately grown there, was first noticed in 2004 and seen again in 2005 and 2006. Approximately two dozen plants were pulled out each year. This indicates that this vervain is capable of persisting, and potentially spreading, in the region.

Specimen citation. Minnesota. St. Louis Co.: North Star Township, NE¼ SE¼ Sec. 5, T53N R13W, in flower and fruit, 14 Sep 2005, *Pomroy* 2311 (DUL, MIN), determined by David Schimpf and Deborah Pomroy.

*Sedum aizoon* L. (Crassulaceae). Aizoon Stonecrop.

Previous knowledge. *Sedum aizoon* is a succulent herbaceous perennial that is native to northern Asia and grown ornamentally in North America (Clausen 1975). It was reported as escaped in the United States only for Massachusetts (USDA 2006). Scoggan (1978) listed it as escaped in just a few locations in Canada, near settlements in Alberta and Saskatchewan. Clausen (1975) did not include it among the 13 alien species of *Sedum* that he regarded as naturalized in North America. Webb et al. (1993) reported it as locally naturalized in northern and central Europe.

Significance. This is apparently the first report of *S. aizoon* from outside of cultivation in Minnesota and a large surrounding region. The plants were very common over about 700 m<sup>2</sup>, the total area split about equally by a road. On one side of the road these plants were on residential lots, mostly exposed to the sun, and on the other side they grew in the partial shade of a pine plantation on church grounds. Bedrock near the surface makes the soil shallow on much of the occupied area, but the species was also succeeding in soil deep enough to use for normal gardens. The population appeared to be vigorous, as control efforts on the residential side have met with little success. These stonecrop plants grew to heights of 4 dm, and thrived in tall, non-managed herbaceous cover; they also persisted in a non-flowering condition where regular mowing kept them short.

Specimen citation. Minnesota. St. Louis Co.: both sides of Morris Thomas Rd. just W of Piedmont Ave., Duluth, SE¼ SE¼ Sec. 30, T50N R14W, in flower, 25 Jun 2006, Pomroy, Hansen, and Barnes 2321 (DUL).

*Cardamine flexuosa* Withering (Brassicaceae). Woodland Bittercress.

Previous knowledge. Rollins (1993) described *Cardamine flexuosa* as a biennial to short-lived perennial that is native to Europe and introduced to North America. The reported collection sites closest to Minnesota (USDA 2006) include older ones in upper Michigan (Voss 1985). In 2002 and 2003 the apparently first collections from Wisconsin were made, all from horticultural settings in four counties in the southeastern half of the state (Vincent and Lammers 2005, Wisflora 2006).

Significance. *C. flexuosa* was found in the Twin Cities metropolitan area, the apparent first report for Minnesota. These plants were growing in decorative (golden/tan color) crushed limestone pavement in partial sun at a suburban residence. They seemed to be growing as annuals, with fibrous roots and a height of less than 10 cm; such variants have sometimes been given taxon status: *C. debilis* D. Don or *C. flexuosa* subsp. *debilis* O. E. Schulz (Rollins 1993). *C. debilis* has been reported from Iowa (USDA 2006). These weedy (Rollins 1993) inconspicuous plants are easily overlooked and may be more widespread in Minnesota, especially if the seeds were introduced with the crushed rock.

Specimen citation. Minnesota. Hennepin Co.: Plymouth, near center Sec. 32, T118N R22W, in flower and fruit, 3 Jun 2006, Schimpf 421 (DUL, MO), determined by Ihsan Al-Shehbaz 3 Jul 2006.

*Silene csereii* Baumgarten (Caryophyllaceae). Biennial Campion.

Previous knowledge. *Silene csereii* is an annual or biennial native to Europe and naturalized as a weed in northern United States and southern Canada (Morton 2005). Major North American treatments (e.g., Hitchcock and Cronquist 1973; Larson 1986; Morton 2005) described the leaf blades as ranging up to 8.5 cm long  $\times$  4 cm wide.

Significance. A few *S. csereii* plants with blades up to 15  $\times$  8 cm were found in an industrial area of Duluth, Minnesota. The well-drained soil was evidently highly fertile, because members of other weedy species growing on it were likewise robust. Measurement of the *S. csereii* specimens held by MIN revealed several from Minnesota (*Holzinger s.n.*, *Galatowitsch* 268), Wisconsin (*Swanson* 647), and North Dakota (*Brenckle* 1236) with blades 10  $\times$  4 cm to 12  $\times$  5 cm, well above the published upper size range. Whether this larger size has a genetic basis or is geographically limited would require further investigation.

Specimen citation. Minnesota. St. Louis Co.: Rice's Point, Duluth, NE $\frac{1}{4}$  NE $\frac{1}{4}$  Sec. 4, T49N R14W, 2 Jul 2005, *Schimpf* 407 (DUL, MIN).

*Malus baccata* (L.) Borkhausen var. *baccata* (Rosaceae). Siberian Crab-apple.

Previous knowledge. *Malus baccata* is a small tree that is native to much of Asia (Cuizhi and Spongberg 2003). It is cultivated in North America (Bailey 1949) for its white floral display. The fruits are small and not of culinary use. *M. baccata* has been reported growing outside of cultivation in many states in the northeastern United States, as well as Minnesota (USDA 2006) and eastern Canada (Scoggan 1978).

Significance. The two previously known Minnesota collections appear not to be of *M. baccata*; a Goodhue Co. specimen in flower, 1977, *Clemants* 634 (MIN), has very tomentose pedicels, and a St. Louis Co. specimen, 1998, *Walton* 3377 (DUL) has fruits that are far too large, some of which retain some calyx lobes. Both may represent the results of hybridizations with domestic apple, *M. pumila* Miller, in a recent generation. Newer collections from St. Louis Co. appear to be the first *M. baccata* known outside of cultivation from Minnesota. Three trees were found rooted within 1 m of each other on a steep, shaded south-facing ledge of a large outcrop of mafic igneous rock. This spot is surrounded by a mosaic of brushy woodland and herbaceous vegetation across approximately 1 km<sup>2</sup> of bedrock exposures and shallow soils. The trees' location is remote, separated from the nearest settlement, current or historical, by about 1 km (much farther in almost all directions), and not near any road or trail. A concentration of other alien plants with small fleshy fruits (*Rhamnus cathartica* L., *Lonicera* spp.) in the same habitat suggests that birds frequently move seeds to this outcrop, the vegetation of which was otherwise strongly dominated by native species. Avian dispersal from a cultivated source is the most likely explanation for this occurrence of *M. baccata*, which Harris et al. (2002) described as a bird-dispersed species. One tree was 7 cm diameter, one was 2.5 cm diameter, and a non-flowering one was 1 cm diameter. The fruits were lustrous, with one lateral

hemisphere red and the other yellow, up to 9 mm diameter, and devoid of remnant calyx lobes. Some of the largest fruits contained one maturing seed.

Specimen citations. Minnesota. St. Louis Co.: Midway Township, NE¼ SW¼ Sec. 33, T49N R15W, in flower, 10 Jun 2004, *Schimpf 354* (DUL, MIN); same location, fruit ripe, 20 Aug 2005, *Schimpf 411* (DUL, MIN).

## MICHIGAN

*Malus sieboldii* (Regel) Rehder (Rosaceae). Toringo Crab-apple.

Previous knowledge. *Malus sieboldii* is a tall shrub or short tree native to China, Korea, and Japan (Cuizhi and Spongberg 2003). It is cultivated in North America for its ornamental fruit and pinkish white floral display (Bailey 1949). It has been reported from outside of cultivation in Illinois, several northeastern states (USDA 2006), and southern Wisconsin (Wisflora 2006).

Significance. This is apparently the first reported occurrence of *M. sieboldii* outside of cultivation in Michigan. The population inhabited a band near the bottom of a south-facing hill, between a long-established *Pinus resinosa* Aiton plantation above and a wetland below. It consisted of at least 20 mature trees, along with hundreds of saplings and thousands of seedlings. The site was still dominated by native vegetation, although *Elaeagnus umbellata* Thunb. was also established and spreading there. The location of the former logging town of Barclay is about 200 meters to the west.

Specimen citations. Michigan. Ontonagon Co.: Barclay Pond, NW¼ NW¼ Sec. 13, T46N R39W, immature fruit, 22 Jul 2006, *Garske 557* (DUL, MICH); same location, ripe fruit, 16 Sep 2006, *Garske 588* (DUL, MICH).

*Carduus crispus* L. (Asteraceae). Welled thistle.

Previous knowledge. *Carduus crispus* is a weedy Eurasian biennial reported from many central and northeastern United States and eastern provinces of Canada (Keil 2006), but not Michigan, Wisconsin, or Minnesota.

Significance. A population of *C. crispus* apparently represents the first known occurrence of this species in Michigan. It consisted of numerous plants, scattered along both sides of an approximately 260 m length of gravel road. The site is surrounded by National Forest land. Marenisco, the nearest town, lies 9 km away. The population has been able to persist and apparently expand on moist clay-gravel soil, in significant shade from northern hardwoods. Several small clearings adjacent to this road may facilitate this plant's further spread. The population was reported to the Ottawa National Forest in fall 2003, and may be controlled or eradicated in the future.

Specimen citation. Michigan. Gogebic Co.: forest road 8170, Marenisco Township, NW¼ NE¼ Sec. 28, T46N R44W, in flower, 1 Aug 2003, *Garske 413* (DUL, MICH).

## WISCONSIN

*Mimulus moschatus* Douglas (Scrophulariaceae, treated as Phrymaceae by some). Muskflower.

Previous knowledge. *Mimulus moschatus* is native to western North America, where it is part of a complex of 13 very closely related species (Whittall et al. 2006). It also has scattered occurrences in eastern North America, some of which are thought to be escapes from cultivation (Gleason and Cronquist 1991). Some earlier authors considered at least the upper Michigan, Quebec and Newfoundland occurrences to be native (Marquis and Voss 1981), and this species is classified as endangered by the states of Massachusetts and New Hampshire (Natural Heritage and Endangered Species Program 2006; New Hampshire Natural Heritage Bureau 2006). In Michigan it inhabits “Muddy or wet ditches, creeks, springy banks, borders of swamps and ponds; moist openings, trails, and roadsides in woods.” (Voss 1996).

Significance. This is apparently the first report of *M. moschatus* outside of cultivation in Wisconsin. At this site it was occasional to abundant in ditches and woods edges along a highway and several gravel side roads. This highway cuts through small seeps and intermittent stream beds; seasonal and permanent residences are fairly frequent along it. Given that this species has long been in cultivation (Pennell 1935) and that the area in which it was found has long been settled, it seems more likely that this *M. moschatus* population is introduced, rather than native but just recently discovered.

Specimen citations. Wisconsin. Bayfield Co.: along state highway 13 ca. 1 km N of Whiting Rd., Bayview Township, SE¼ NE¼ Sec. 33, T50N R4W, in flower, 3 Jul 2001, *Garske* 253 (OSH, WIS); same location, 6 Jul 2001, *Garske* 266 (DUL).

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## THE BIG TREES AND SHRUBS OF MICHIGAN

### 51. *Quercus robur* L. English Oak

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The largest known English Oak in Michigan is located near Benzonia in Benzie County in the northwest part of Michigan's Lower Peninsula.

*Description of the Species:* English Oak leaves have rounded lobes like those of a White Oak. English Oak leaves can be readily distinguished by the ear like lobes at the base of the leaf blade (see Fig. 1) and by their being sessile or nearly so (Barnes & Wagner, 2004). The leaves are 5–13 cm. long and 3–6 cm. wide (Miller & Lamb, 1985). They are glabrous and dark green above and pale bluish green on their undersurface. The acorns are 1/3 (or less) enclosed by their caps and are borne singly or several on long slender peduncles which may reach lengths of 2–5" (Krüssman, 1986). The bark is dark gray and deeply furrowed. English Oaks are natives of England and Western Europe. They are usually wide spreading trees and are frequently cultivated (Sargent, 1965). The narrowly columnar cultivar 'fastigiata' (Dirr, 1983) is frequently planted, particularly near buildings.

*Location of Michigan's Big Tree:* The state champion English Oak is located on Case Rd. just 0.1 mi. south of Homestead Rd. To reach the tree take Rt. 31 to the southern side of Benzonia. Turn left on Homestead Rd. (County Rd. 608). After about a half mile you will come to Case Rd. The tree is on a curve on Case Rd. opposite # 1091 Case Rd. The tree is 33' off the west side of the road. The GPS coordinates for this location are N44°36.966' × W86°05.347'.

*Description of Michigan's Big Tree:* The tree has a single, solid, healthy trunk. Measurements were made on July 10, 2004. The girth at 4½' above the ground was 160" (13' 4"). Its height was 75' and its average crown spread was 58'. The total points for this tree (G + H + ¼ C.S.) thus are 160 + 75 + 15 = 250. When previously measured in 1976 it had a girth of 155" a height of 81' and an average crown spread of 76'. The tree has continued to add girth while losing some of its height and crown spread. The tree has a luxurious colony of Periwinkle (*Vinca minor* L) growing around its base. It has a prominent fire scar and a rotting strip below a branch sawed off about 5' above the ground.

The tree has a split rail fence in front of it. A sign attached to the fence indicates that the tree was adopted by the Benzonia Garden Club as a conservation project. The sign gives the following history of the tree: "The acorn which produced this tree was carried from Beverly, MA by Henry B. Balch in 1867. It was harvested from a tree which was in turn produced from an acorn brought by his

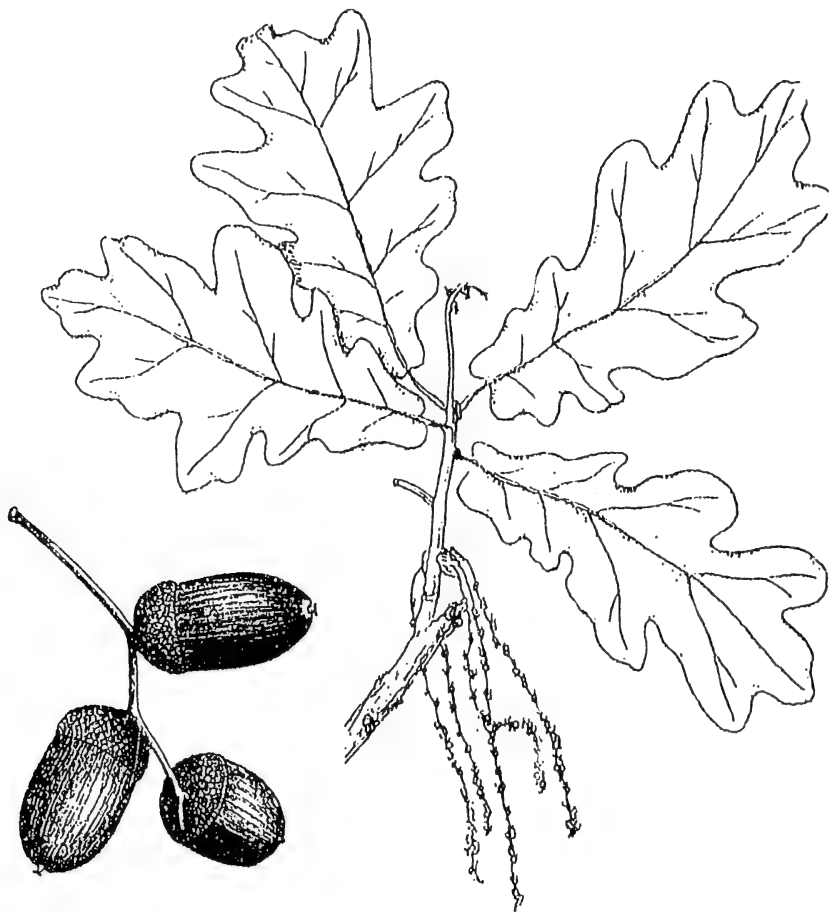


FIGURE 1. Twig, leaves, male flowers and fruits of the English Oak. The twig and leaves are modified From Gleason (1952). Note the ear-like lobes at the bases of leaves ( $3/4 \times$ ). The fruits are modified from Krüssman (1986). Note that several acorns may be borne on a single, elongated, zig-zag peduncle ( $3/4 \times$ ).

father from Horton, Somerset, England. The tree in front of you was planted in 1869 by Henry's son, Herbert C. Balch, when he was eight years old." The tree has been growing here ever since.

### INVITATION TO PARTICIPATE

If you would like to join in extending this series of articles by visiting and describing one or more of Michigan's Big Trees, please contact Elwood B. Ehrle (woodyehrle5098@sbcglobal.net) for help with locations, specifications for tak-



ing measurements and assistance with the manuscript. The Michigan Botanical Club encourages your involvement with this activity. Please remember to ask permission before entering private property. For a list of Michigan's Champion Trees and Shrubs, see Ehrle (2003).

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## THE BIG TREES AND SHRUBS OF MICHIGAN

### 52. *Cercis canadensis* L.

#### Eastern Redbud

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The largest known Eastern Redbud tree in Michigan is located in Wayne, MI in Wayne County in the southeast portion of Michigan's Lower Peninsula.

*Description of the species:* The Eastern Redbud is a small tree in the family Fabaceae (formerly Leguminosae). It can be easily recognized by its bilaterally symmetrical bright pink flowers which appear during April–May before or with the leaves. The fruit is a 2–3" pod or legume which develops during June but is persistent and usually abundant on the trees during the winter. The leaves are broad, heart-shaped, and entire (See Fig. 1). The twigs are slender and zig-zag. Native Eastern Redbuds reach their northern limit in Southern Michigan (Voss, 1985). They are much more abundant further south and are particularly noticeable in the Appalachian mountains during the spring. They are, however, widely planted and hence occur further north than their native range. A white-flowered form (var. *alba*) is known (Dirr, 1983) but is infrequently seen. There is only one listed in the "Michigan Big Tree and Shrub Inventory". It was recently reported by Robert Bloye as present on the Michigan State University campus in East Lansing, MI.

*Location of Michigan's Big Tree:* The State Champion Eastern Redbud is located in front of the Annapolis Hospital in Wayne, MI. The tree can be reached by taking I-94 east to the Wayne Road exit.

Turn left (N) and follow this to Van Born. Turn right (E) and follow Van Born to Veney Rd. Turn left and go to Annapolis Rd. Turn left. The hospital entrance is on the left at 33155 Annapolis Rd. The tree is directly in front of the hospital.

*Description of Michigan's Big Tree:* The tree has a solid healthy trunk. The tree was measured by Gail McPherson and Richard Pomorski in 2004. The girth at  $4\frac{1}{2}'$  is 113". The height is 26'. The average crown spread is 35'. The total number of points ( $G + H + \frac{1}{4}$  C.S.) for this tree is, therefore,  $113 + 26 + 9 = 148$ . The 2004–5 National Champion tree is in Topeka, KS. It has a girth of 92", a height of 39' and an average crown spread of 40'. The total number of points for the National Champion tree is  $92 + 39 + 10 = 141$ . The Michigan tree is larger and will be submitted to American Forests for consideration as a new National Champion Tree.



FIGURE 1. Documented Distribution in Michigan and Characteristics of the Eastern Redbud. The map is from Voss (1985). The asterisk shows the location of Michigan's Champion tree. The illustrations are from Barnes and Wagner (2004). 1. Winter twig,  $\times 1$ . 2. Portion of twig, front view, enlarged. 3. Portion of twig, side view, enlarged. 4. Leaf  $\times \frac{1}{2}$ . 5. Flowering twig,  $\times 1$ . 6. Vertical section of flower, enlarged. 7. Fruit, legume,  $\times \frac{1}{2}$ .

### INVITATION TO PARTICIPATE

If you would like to join in extending this series of articles by visiting and describing one or more of Michigan's Big Trees, please contact Elwood B. Ehrle (woodyehrl5098@sbcglobal.net) for help with locations, specifications for taking measurements and assistance with the manuscript. The Michigan Botanical Club encourages your involvement with this activity. Please remember to ask

permission before entering private property. For a list of Michigan's Champion Trees and Shrubs see Ehrle (2003).

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## BOOK REVIEWS

**Mayewski, Paul Andrews and Frank White. 2002. *Ice Chronicles: The Quest to Understand Global Climate Change*. University Press of New England, Hanover, NH. pp 233. ISBN-1-58465-061-3. \$19.95 Paperback.**

The *Ice Chronicles* are the stories told by the vast annual layers of ice and snow in glaciers and continental ice sheets scattered around our globe, the stories of the climates this world has experienced through the past 110,000 years. [This record is now traced back through the past 740,000 years in the ice cores from Dome C, Antarctica (Nature: 429, 623–628).] Understanding these chronicles gives us a glimpse into how climate has operated in the past and helps us understand its current trends and how we are influencing these trends.

In the first four chapters of this book, the authors tell how our civilization has historically viewed climate, as a rather static and invincible part of our world, and how that view has now changed in the past few decades. They relate the story of the Greenland Ice Sheet Project Two (GISP2) expedition from its inception as a dream for a more complete record of earth's climate history to its culmination in the collection and analysis of the ice cores. Paul Mayewski, as the chair of the GISP2 project, gives the story a personal touch, allowing the reader to experience the major events of the expedition through his eyes.

The authors then explain the major trends in the data collected from these cores and show how they can reconstruct past climate conditions and changes from the chemical composition of the particles and gas bubbles in the ice. Studying the ice cores, they discovered that the climate is not the static, reliable system we once thought. Instead, it is prone to Rapid Climate Change Events (RCCEs), which can produce a significant climate change as quickly as in a few years. These changes are the result of many climate-forcing factors working together. As they look at the RCCEs that occurred during the Holocene, the authors propose these climate changes as factors contributing to the collapse of past colonies and even entire civilizations, such as the Norse colonies in Greenland and the Mayas in Central America.

In the last four chapters, the authors take a detailed look at the climate changes during the past thousand years. They explain the trends and indicate that the ice core record shows a significant change in its chemical composition during the post-industrial age. These changes indicate more than just global warming or global cooling. They are evidence of a destabilizing of the climate, setting the stage for increasingly more unpredictable RCCEs in the future. One of the many factors influencing this shift in climate stability, the authors believe, has been the changes humans make to the atmosphere's composition. They also discuss our civilization's response to this idea that humans are helping to change our climate. The authors trace how we have dealt with this question in the past through the avenues of science, politics, and public policy. They propose a way of dealing with this issue: a balance between trying to reduce our impact on the climate, trying to reverse the changes we have already made, and learning to live

with a dynamic, rapidly changing climate system. The authors broaden their plea for a responsible use of and care for this Earth to the many other environmental issues we face today, not just this current global warming issue. They challenge us to learn from our past and use that information to live in a way that minimizes our impact on this planet and allows us to adapt to the naturally occurring climate changes we will face as a civilization.

Throughout this book, the authors mix the stories of how the human race has looked at climate and of the current efforts to further understand climate through ice cores with the data that tells us how and why climate changes occur. They explain the science behind the statements many scientists make about global climate change, the politics behind the politicians' opinions about global warming, and the misconceptions and ideas behind many public policies, in a way that an amateur scientist would easily understand. They present a balanced view of the many sides to this issue of global climate change, making sure the reader understands that control of the climate system is based on many factors we do not fully understand. Interspersed through the book are short stories of Paul Mayewski's experiences and the people who have greatly influenced his career. These stories are a delightful look into an explorer and scientist's life. Other inserts are explanations of technical aspects of the quest for an understanding of climate change, which are helpful in understanding the science behind this book. Overall, this is a well-written, easy-to-read book that is packed with information. This book helped me understand the issues behind the global warming controversy more clearly and with a more comprehensive view of the many contributing factors. It is the most balanced, science-based, and reasonable response to the global warming debate I have ever read.

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**Lomolino, Mark V., Riddle, Brett R., & Brown, James H. 2006. *Biogeography*, 3<sup>rd</sup> ed. Sunderland, MA: Sinauer Associates. 845 pp. ISBN 978-0878930623, \$92.95 (Hardbound).**

*Biogeography* is a title that aptly sums up the scope of this excellent introductory textbook. This new third edition is updated with over 1000 new publications from the field. Science is progressively becoming more interdisciplinary, a fact which this textbook reflects. *Biogeography* was written for undergraduate students, but is a great resource for anyone interested in the distributions of plants and animals we see today.

The text is divided into six units covering major areas of biogeography. The authors begin with a two-chapter unit, *Introduction to the Discipline*, giving a brief introduction to the field and a history of the development of biogeography as a modern scientific discipline. They follow this introduction with a second unit, *The Environmental Setting and Basic Biogeographic Patterns*, which includes three good background chapters detailing foundational concepts neces-

sary to the study of biogeography. For non-biologists, these chapters are very good summaries of concepts in ecology and geology. The third unit, *Earth History and Fundamental Biogeographic Processes*, covers the interplay between earth history and biogeographical processes such as dispersal and speciation. This unit includes a very good chapter summarizing what we know about Pleistocene glaciation. Since evolution is a key component of the modern field, the authors include a three-chapter unit, *Evolutionary History of Lineages and Biotas*, on techniques used to unravel evolutionary history. A fifth unit, *Ecological Biogeography*, covers a range of subjects including island biogeography, areography, ecogeographic rules, and diversity gradients. Finally, Unit 6, *Conservation Biogeography and New Frontiers*, expands upon biodiversity and extinction, conservation biogeography, and new frontiers of the field.

Even though this is a text about biogeography, its style of writing appeals to people of all backgrounds and interests. The authors come from a primarily zoological background, but they include many examples of biogeographic concepts using various kinds of organisms ranging from mammals, to invertebrates, to aquatic organisms, to plants. Since vegetation is a key component of terrestrial biomes, many chapters include botanical examples. For instance, Chapter 10 extensively covers the mapping of biogeographic regions, with many of these maps being based on the distribution of land plants. Chapter 9 develops ideas relating to plants' response to glaciation. Plant examples are sprinkled throughout the entire text.

The authors are the first to point out that research in some areas, such as the marine realm, has lagged behind the study of terrestrial areas. They carry this honest view of their field throughout the entirety of the text as they examine all major theories in a critical light, thereby lending to the credibility of the book and science as a whole. Not only do the authors more than adequately cover past and current ideas in biogeography, they present these ideas in a way to stimulate the reader to look beyond what is known. For example, the text not only discusses MacArthur and Wilson's classic Equilibrium Theory of island biogeography, it also presents pros and cons various scientists have advanced and even points out the need for a new theory to encompass biogeographers' subsequent observations. In fact, the authors devote a whole chapter, the last one, to the frontiers of biogeography.

This book also includes a very complete glossary of important terms, an extensive bibliography, and an index. In the text, the authors are constantly referring to primary literature, which is reflected in the full 50 pages of two-column bibliographic citations. This is an extremely helpful feature for anyone who wants to investigate the papers behind the ideas presented in the textbook. Inside the book, the illustrations and maps are all grayscale, with the endpapers being the only full-color illustrations in the text. The front endpaper is Wallace's (1876) scheme of biogeographic regions. The back endpaper is a beautiful map of the world illustrating many of the oceanic and terrestrial topographic features covered in the text. The many grayscale illustrations more than make up for the lack of colored graphics. For example, Chapter 9, which covers Pleistocene glaciation, has a table or figure on 38 out of 48 pages. In fact, one of the most

helpful features of this text is the many illustrations, which give real-world examples and greatly aid in understanding key concepts.

The reasonable price, relative to other textbooks, belies the wealth of information packed into *Biogeography*. The text is clear and well-written, full of examples of concepts. Overall, this book is a valuable addition to the reference shelves of those who study and teach biology and would be a fascinating, though more technical, read for anyone interested in understanding the patterns in the diversity of life we see today.

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On the cover: *Black oak savannah at Hoosier Prairie (Lake County, Indiana).*  
*Unlike tall grass prairies to the west, grasses such as*  
*Andropogon gerardii (left) are a minor component of this community.*  
*Instead broad-leaved species such as Comptonia peregrina (2 center images) and*  
*Rubus hispida (2 right images) form a diverse, dense ground layer.*

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## ARBUSCULAR MYCORRHIZAL FUNGAL ROOT COLONIZATION AND INOCULUM PROPAGULES IN DECIDUOUS FLOODPLAIN FORESTS OF SOUTHWESTERN MICHIGAN, USA

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### ABSTRACT

We examined the arbuscular mycorrhizal (AM) fungi of temperate deciduous floodplain forests in southwest Michigan, USA, and the relationship between soil moisture and AM fungal root colonization and inoculum. In four floodplain forests, AM root colonization was measured for roots collected from soil samples taken along soil moisture, micro-topography and vegetation gradients. An AM fungal inoculum bioassay was also conducted using these samples to measure the amount of infective propagules found across these gradients. Although soil moisture had no significant effect on either AM parameter measured, the effect of forest site was significant in most instances. We also found a significant positive relationship between AM infective propagules and root density. Overall, this study illustrates that AM fungi are distributed throughout these temperate floodplain forests even in the potentially most anoxic, highly saturated low lying portions of the floodplain.

**KEY WORDS:** Arbuscular mycorrhizal fungi, floodplain forests, riparian, soil moisture

### INTRODUCTION

Floodplain forests in much of the world (Terborgh and Andresen 1998) consist of trees that associate with arbuscular mycorrhizal (AM) fungi. As in most forests, AM fungi of floodplain forests likely serve roles in the mineral nutrition of host plants and belowground carbon allocation. In addition, floodplain AM fungi appear to be especially important in riparian habitats as they can link terrestrial and aquatic ecosystems by contributing significant amounts of protein to the nutrient budgets of rivers (Harner et al. 2004). However, how AM fungi are distributed across the complex soil hydrological, geo-morphological, and vegetation gradients that characterize floodplain forests is not clear.

Floodplain forests exhibit a dynamic soil hydrology and flood pulses can differentially impact soil moisture levels (Mitsch and Gosselink 1993) resulting in soils that are mosaics of saturation in space and time. Soil saturation, and conversely soil aeration, may be a key factor affecting AM fungi as anoxic conditions are considered detrimental to AM fungal growth (Mosse et al. 1981; Pawlowska and Charvat 2002; Entry et al. 2002) and soil flooding can limit the colonization of AM fungi in grasses of oligotrophic shrub wetlands (Miller 2000; Miller and Sharitz 2000). However, other studies have shown higher AM

fungal spore counts in poorly drained soils (Khalil and Loynachan 1994; Troeh and Loynachan 2003) and no relationship between soil moisture and AM fungal colonization in prairie pothole wetlands (Wetzel and van der Valk 1996) or native plants of calcareous wetlands in New York (Van Hoewyk et al 2001). In flooding pampas grasslands of Argentina, duration of flooding impacted root colonization but not spore density (Escudero and Mendoza 2005). These latter studies suggest that factors such as vegetation distribution or soil nutrient levels may determine the distribution of AM fungi in floodplains.

Since the AM fungi of floodplain forests have been little studied and these forests differ from other wetlands such as by having a preponderance of woody plant root systems, the factors that influence AM fungi in these important ecosystems remain unclear. Therefore, the objective of this study was to examine how AM fungi are distributed in temperate deciduous floodplain forests of the Kalamazoo River in southwest Michigan, USA, and to test the prediction that the colonization of roots by AM fungi and their abundance of infective propagules should be low in low-lying often saturated soils of floodplain forests but higher in more aerated zones. Alternatively, if factors other than soil moisture such as vegetation or soil nutritional gradients are more important, then clear relationships between soil moisture and AM fungi may not exist. To test these predictions, we examined the relationships between AM fungal root colonization and inoculum propagules, root density, soil moisture, and a multi-factor ecological zone concept characterized by micro-topography and vegetation.

## METHODS

### Sites

We examined four study areas in temperate floodplain forests along the Kalamazoo River in Kalamazoo County, Michigan, USA (in order from upstream to downstream): the Augusta Floodplain Reserve (AUG; 42°19'N and 85°21'W); the Galesburg-Augusta High School River Preserve (GAL; 42°16'N and 85°25'W); the Comstock Preservation Area (COM; 42°17'N and 85°31'W) and the Kalamazoo Nature Center (KAZ; 42°21'N and 85°34'W). These forests consist of deciduous tree species such as *Acer saccharinum* L., *Fraxinus* spp., and *Ulmus americana* L. as well as the less prevalent *Plantanus occidentalis* L. and *Gleditsia tricanthos* L. that grow along a complex soil-hydrologic and geo-morphological gradient. This gradient ranges from low-lying moist, potentially anoxic soils that are often annually flooded and are virtually devoid of herbaceous ground cover to higher areas containing somewhat drier soil, abundant herbaceous vegetation and more diverse tree communities. Conceptually this mosaic of vegetation and geomorphology resembles models proposed to describe other riparian ecosystems (Lindsey et al. 1961; Gregory et al. 1991; Merritt and Lawson 1992; Mitsch and Gosselink 1993). Mean annual precipitation is about 100 cm and mean annual temperature is about 9.4°C. The closest US Geological Survey river hydrology gauging station to these sites has measured 30 historic crests (near bank-full to exceeding flood stage) in the last 70 years ([www.crh.noaa.gov/grr/ahps/RiverDat/E19s/cmsm4.crests](http://www.crh.noaa.gov/grr/ahps/RiverDat/E19s/cmsm4.crests)).

### Soil sample locations

We collected soil samples from three ecological zones that characterize these floodplain forests. In the lowest lying areas, where soil appeared to be nearly saturated or had been inundated for the longest period, herbaceous vegetation was generally absent except for an occasional aquatic macrophyte. The tree canopy here was dominated by *A. saccharinum*. These micro-topographic depressions were often inundated during over-bank water flows or rises in the water table. We designated this habitat as "wet zone." The other clearly distinguishable habitat was higher and contained drier soils, dense herbaceous vegetation, a varying degree of shrub cover and canopy dominants that in-

cluded *A. saccharinum* as well as *Fraxinus* spp., *U. americana*, and *Tilia americana*. Here, flooding is thought to occur only during the greater flood pulses. We designated this habitat as "dry zone." Between these two habitats we typically found areas of transition that were variable in shape and scale relative to the other zones but did not always exist if topography changed abruptly. These habitats contained sparse herbaceous vegetation, moderately moist soil and a sloping topography. We designated these zones as "transition."

Samples were collected from 13–20 October 1994. Within each floodplain location (AUG, GAL, COM, KAZ) two sampling transects were selected that contained the three distinct ecological zones described above. Within each transect, two soil samples were extracted from each of the three zones. Thus, a total of 48 samples (4 locations  $\times$  2 sampling transects  $\times$  3 zones  $\times$  2 soil samples/zone) were collected. Sampling sites within an area were selected at points 1/3 and 2/3 along the length of the wet zone. Sampling sites for the transition and dry zones were then taken from points perpendicular to those in wet zone sites, approximately in the middle of each respective zone. If the dry zone often extended quite far (e.g., >20m), the sample site was marked >5m beyond the transition zone.

### **Soil sampling**

Soil samples at each site were extracted with a "cup cutter" (a tool used by golf course greens keepers to make holes) with a diameter of 10.8 cm and set to a depth of ~14.5 cm. The extracted cores were placed in a polyethylene bag and stored at 4°C. Each core was divided into three parts: Half for a mycorrhizal inoculum bioassay; one quarter to measure AM root colonization of in situ roots; and one quarter to determine soil moisture content and soil organic matter content, the latter measured as a part of a parallel study focused on describing the vegetation patterns in these forests and that also measured several other environmental features of each sampling site including the relative elevation and plant community composition and biomass (Avis P.G., Foster S. and Olexia P.D., unpublished).

### **Soil moisture**

Soil moisture content was determined gravimetrically (Brower and Zar 1977). Thirty grams of homogenized soil sample were dried at 105°C for 24 h. The dry mass was determined and the percent soil moisture was calculated relative to the wet mass.

### **Root clearing and staining of AM fungi**

Fine roots (<2 mm diameter) were autoclaved in 10% KOH for 10 minutes at 121°C to clear root cells of cytoplasm and rinsed with deionized water several times. Darkly pigmented roots required additional clearing and were bleached with 50% bleach acidified with a few drops of 5N HCl (Bevege 1968) and then acidified overnight in a 1% HCl solution (Koske and Gemma 1989). Fine roots were stained in 0.02% trypan blue in a 1:2:2 solution of lactic acid, glycerol and deionized water (Kormanik and McGraw 1982) in the autoclave for 15 min at 121°C and destained in 50% glycerol.

### **Root density**

Total root length for each core was estimated by a modified Newman technique described by Tennant (1975). All roots were extracted from the sub-samples and fine roots were separated from larger diameter roots. The lengths of larger diameter roots were measured directly with a ruler. Stained fine roots were then cut into fragments not exceeding 2.54 cm, and placed in petri dishes containing destain solution. Root-line intersections were counted and counts were done five times for each sample and were then converted to root length (cm) using the formula described by Tennant (1975). Root density was determined by dividing root lengths by the volume of sample soil used, which had been determined by measuring how much water of a known volume the original soil core had displaced.

### **In situ root colonization by AM fungi**

Root length colonization by AM fungi was determined on ~10 cm of randomly selected root fragments from each sample following a slightly modified technique reported by Kormanik et al. (1980). Roots with 1–33% of the width colonized by AM hyphae, hyphal coils, vesicles and/or arbuscules

were scored as "1", 34–66% colonization were scored as "2" and 67–100% colonization were scored as "3." Only roots with cortex were scored.

#### **AM fungal inoculum bioassay**

An AM fungal inoculum bioassay was conducted to measure the arbuscular mycorrhizal fungal propagules of sample soils following a similar protocol as in Corbin et al. (2003). Soil was homogenized by hand (shaking the bag) and, in duplicate, ~135 ml of each sample were placed into containers (Stuewe and Sons, Inc., Corvallis, Oregon, USA) that were surface sanitized (soaked in 10% bleach for 10 minutes). Controls (sand, Consumers Sand and Concrete, Comstock, Michigan, USA; and autoclaved surplus sample soil) to check for contamination were set up similarly. Un-germinated hybrid *Zea mays* seeds (Early Golden Bantam, American Seed, South Easton, Massachusetts, USA) were placed in the top 1 cm of each filled container and allowed to grow in a greenhouse. Plants were grown under ambient light supplemented by full spectrum growth lights (cycles of 16 hours of light, 8 hours of dark) and watered to field capacity approximately every other day. Plants were grown for three weeks and then roots were harvested, cut to 1 cm lengths, and stored in isopropyl alcohol before staining.

AM fungi associated with bioassay roots were stained following a method modified after Brundrett et al. (1994). Cytoplasm of root cells was cleared by autoclaving at 121°C at 20 psi for 3 min in 10% KOH. After rinsing twice with deionized water, roots were stained for 24 hrs at room temperature (20°C) in 0.3% Chlorazol black E in a 1:1:1 solution of lactic acid, glycerol and deionized water. To destain, roots were transferred to a 50% glycerol solution for 24 hrs at room temperature.

For each bioassay sample, we analyzed from 40–100 cm of root for the number of colonization units formed from single entry points per length of root observed. The total root length examined varied since the samples did not have equal amounts of root growth. Ten of the stained 1 cm root fragments were placed parallel to each other in 50% glycerol on a microscope slide and between 4 and 10 slides were made per plant depending on the amount of root produced by the time of harvest. Slides were examined microscopically at 40× and 100×. Colonization units were determined as in Corbin et al. (2003), which were counted as the number of separate clusters of appresoria, hyphae, arbuscules, and/or vesicles developed during primary colonization of the root.

#### **Statistics**

After checking for normality and log-transforming non-normal data, we tested the effect of zone, soil moisture, site and transect on root density, mycorrhizal score and bioassay root colonization by analysis of covariance. Zone, site and transect were considered fixed effects and soil moisture and the log of root density (where it was added as an independent variable) as continuous covariates. Models were developed to examine the joint and separate impacts of zone and soil moisture while controlling for site and transect. We also tested the impact of root density in regressions of mycorrhizal score and bioassay root colonization. For our analyses we used PROC MIXED in SAS (v8.2; SAS Institute Inc., Cary, North Carolina, USA); the correlations among root density, mycorrhizal score and bioassay root colonization were also computed with PROC CORR.

## **RESULTS**

Soil moisture was not significant in any of the regressions we tested (Table I). However, soil moisture was significantly correlated to zone (mean gravimetric soil moisture for all sites was 54.5, 46.2, and 38.7% for the wet, transition and dry zones, respectively; Pearson correlation = -0.58,  $p < 0.0001$ ) and zone had a significant effect on log *in situ* root colonization when moisture was removed from regression and when root density was included (Table I).

For log root density, log *in situ* root colonization and log bioassay root colonization, the effect of site was significant in most regressions but the effect of transect was significant only for log root density and log *in situ* root colonization



TABLE I. Regression statistics for log root density, log *in situ* root colonization and bioassay root colonization. Values are those from regression models that include all effects listed except for root density or unless indicated otherwise. Where log root density is listed as an effect, values include those models that included root density, site, transect and zone. Regressions significant in complete model were also significant when regressions did not include root density and zone (if not included). \*, \*\*, \*\*\* indicate p-values <0.05; <0.01; <0.001, respectively.

Parameter Effect	df	F	p-value	
<b>Log root density</b>				
Soil moisture	1,36	2.33	0.1355	
Zone	2,36	0.44	0.6494	
Site	3,36	7.01	0.0008***	
Transect(Site)	4,36	2.92	0.0342*	
<b>Log <i>in situ</i> root colonization</b>				
Soil moisture	1,34	0.24	0.6281	
Zone	2,34	2.31	0.1146	
Zone	2, 35	3.38	0.0454*	(soil moisture not included)
Zone	2,34	4.03	0.0268*	(root density included but not soil moisture)
Site	3,34	1.98	0.1357	
Site	3,34	3.29	0.0322*	(root density included)
Transect(Site)	4,34	3.29	0.0222*	
Transect(Site)	4,34	4.64	0.0043**	(root density included)
Log root density	1,34	3.20	0.0825	
<b>Log bioassay root colonization</b>				
Soil moisture	1,31	0.33	0.5713	
Zone	2,31	0.50	0.6138	
Site	3,31	4.60	0.0089**	
Transect(Site)	4,31	1.28	0.2973	
Log root density	1,30	15.78	0.0004***	

(Table I). Figure 1 illustrates the impact of site on the distribution of these parameters in relation to zone. Each site appeared to have distinctive root densities that varied independent of zone. *In situ* root colonization and bioassay root colonization tended to increase from wet to upland in most sites but sites generally had different levels of each of these parameters. For example, the COM site had the highest and the KAZ site the lowest overall root density with GAL and AUG sites intermediate. In contrast, KAZ and AUG sites had the highest but COM and GAL the lowest *in situ* root % AM fungal colonization; and the COM, GAL, and AUG sites had higher bioassay root colonization than the KAZ site.

Root density was significantly positively correlated to bioassay root colonization (Pearson correlation = 0.70,  $p < 0.0001$ ) but *in situ* root colonization was not significantly correlated to root density or bioassay root colonization.

## DISCUSSION

AM fungi colonized roots and AM fungal inoculum was found in soils collected from all three ecological zones of the floodplain forests we examined even in the low-lying, relatively saturated "wet" zone. Although soil moisture was strongly correlated to the zone gradient along which we sampled and mycor-

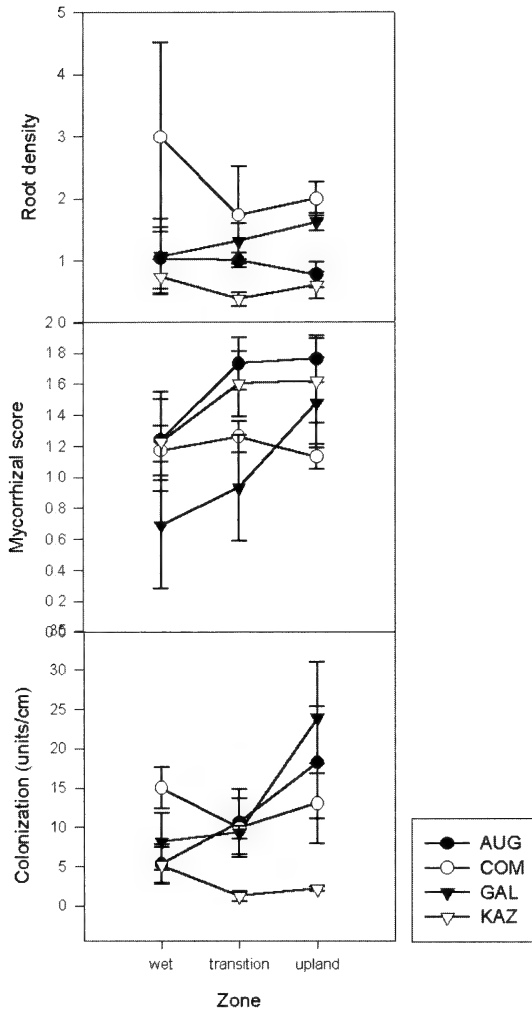


FIGURE 1. Mean root density ( $\text{cm}/\text{cm}^3$ ), *in situ* percent AM fungal root colonization (mean mycorrhizal score) and inoculum bioassay root colonization (infection units/cm root) in each site. Bars represent s.e.

rhizal parameters tended to be higher in the “dry” zone, soil moisture had no statistically significant effect on any of the mycorrhizal parameters tested. Therefore, our study provides little support for the hypothesis that saturated soils inhibit root colonization or inoculum production by AM fungi in these forests. Two caveats are important to consider, though. We measured soil moisture and mycorrhizal parameters at only one time and the impact of saturation may be more evident at other times of the year such as during spring floods. Also, our bioassay only tested for the presence of inoculum and not the direct influence of soil saturation on the production and/or infectiveness of inoculum. But, even if

soil moisture does impact AM fungi at times other than when we measured, inoculum was present in the most saturated soil we sampled possibly because flood pulses moved propagules from higher to lower areas of the floodplain landscape (Miller 2000; Wetzel and van der Valk 1996; Kahlil and Loynachan 1994) and/or when stressed AM fungi produced more inoculum (Rickerl et al. 1994). As a result, this inoculum could ensure colonization of host roots when moisture levels become favorable for AM development.

The floodplain forest AM fungi studied here are similar to those in other wetlands (e.g. Wetzel and van der Valk 1996) in that they appear to be impacted by factors other than soil saturation. In our study, site and ecological zone appeared to be important. Site had a consistent effect on all parameters indicating that the floodplain forests from which we sampled were quite different environments for AM fungi. For example, despite having relatively high *in situ* root colonization, the KAZ site had very low colonization in inoculum bioassays. These site differences may result from differences in the component species of the AM fungal communities and/or vegetation as vegetation patterns differ between sites (Avis, Foster and Olexia, unpublished). Similarly, within site differences may also explain the significant effect of transect on root density and *in situ* root colonization. Zone also had a significant effect on *in situ* root colonization and this effect was even more pronounced when root density was included in the regression. Our zonal concept encompassed multiple factors. We believe that at least for AM fungal colonization of floodplain roots, the zone concept provided a surrogate measure for factors such as host plant type and root growth characteristics which are likely important to AM fungal distribution in these forests regardless of soil moisture levels. Other important factors this concept may incorporate include soil nutrient and/or soil contamination (e.g. PCB's from industrial activity along the river). We were not able to measure either of these factors but both may vary along these same gradients.

An interesting and unexpected result we found was the significant positive relationship between root density and AM inoculum. This suggests that roots serve as important vectors of AM inoculum in these forests which is consistent with the understanding that AM fungal inoculum includes spores as well as hyphae from infected roots (Harley and Smith 1983). However, the lack of relationship between root density and *in situ* root colonization suggests that the infective component of roots is extra-radical (e.g. hyphae attached to but outside the root) and that the abundance of infective extra-radical hyphae was not directly related to the AM fungal colonization structures we examined in the cortex of the roots.

AM fungi are distributed throughout the floodplain forests we studied but a clear relationship to soil moisture was not found. As a result, the *potential* influence of floodplain AM fungi to plant growth and carbon sequestration in floodplains and to link terrestrial and aquatic components of riparian ecosystems appears widespread.

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**THE FIRST OCCURRENCE OF THE  
GREEN ALGA *PARALLELA NOVA-ZEALANDIAE*  
(CHLOROPHYTA, TETRASPORALES) FROM MICHIGAN**

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ABSTRACT

The green alga *Parallela nova-zealandiae* is described from two Michigan locations. A comparison with and its possible relationship to the genus *Radiofilum* are discussed.

**KEYWORDS:** *Parallela*, Tetrasporales, *Radiofilum*, green algae

INTRODUCTION

There are numerous genera of green algae (Chlorophyta) living in freshwater habitats. Reports of their distribution in North America have been scattered throughout the algal literature for a long time including the work of Prescott (1962) for the western Great Lakes. These reports been summarized only recently for North America (Wehr & Sheath 2003).

This paper reports the occurrence in Michigan of the green alga *Parallela novae-zealandiae* Flint, a species first described from New Zealand (Flint 1974).

METHODS AND MATERIALS

Oak leaves and small twigs with attached *Parallela* were collected from Stoney Lake, Kalamazoo Co. and the north arm of Lake Geneserath, Beaver Island, Charlevoix Co., Michigan in late June 1968 and early July 1990, respectively. Observations were made with an AO or Zeiss Photoscope II microscope from both freshly collected material and from short term cultures grown in soil water extract or Bold's Basal Medium (Bold 1967) with additional soil water extract. Attempts to maintain cultures for extended periods failed; cultures no longer survive.

RESULTS AND DISCUSSION

An alga, first determined as *Homospora transversalis* de Brébisson (1839, 1844) was collected in late June 1968 from Stoney Lake. The algae grew attached to the under surface of a floating dead oak leaf. The largest plant was visible to the unaided eye and smaller ones with a hand lens. The alga was later identified as *Parallela novae-zealandiae* Flint, an organism first described from the South Island, New Zealand (Flint 1974). It was later reported from the North Island, New Zealand (Taylor 1975). Subsequent reports include Denmark (Chris-

tiansen 962) as *Radiofilum transversale* (de Brébisson) Christiansen, the States of Minas Gerais and Rio de Janeiro, Brazil, South America (Santa Anna et al. 1979), Kansas, U.S.A. (Reinke 1983), and most recently Australia (Entwisle 1989; Entwisle & Skinner 2001).

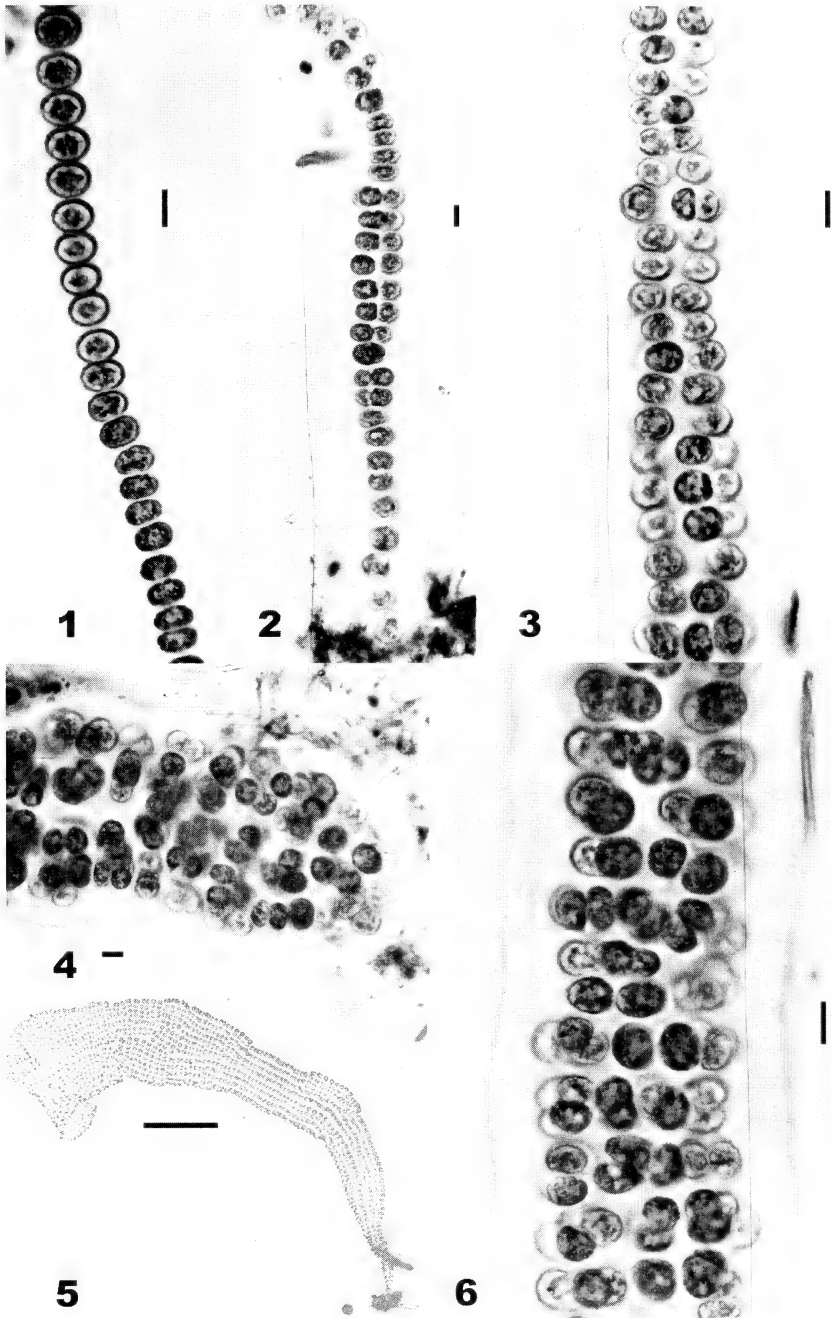
The alga is filamentous to slenderly clavate and gelatinous. Young plants have a uniseriate arrangement of cells enclosed by a continuous gel equal in thickness to the cell diameter (Fig. 1). The attached end appears to remain uniseriate for a length of six to eight cells during early growth. Above this area longitudinal divisions produce a biseriate condition (Fig. 2) and still higher additional longitudinal divisions produce a tiered arrangement of four cruciately arranged cells (Fig. 3). Continued intercalary divisions in which each cell and its progeny accomplish three planes of division produced tiered packets of 16 or more cells. Through secretions of gel by each cell they eventually spread apart, at first laterally in the plane of the tier, then through further division and gel secretion the displacement becomes irregular. At the apex of the plant, cells and small groups of cells are scattered irregularly throughout (Fig. 4). During this growth, the outer gel of the plant may become two to three cell-diameters thick and the plant as a whole becomes clavate in shape (Fig. 5).

Each cell has a continuous, thick wall distinct from the surrounding gel (Fig. 6). Within is a parietal, bowl-shaped chloroplast that closely encloses the protoplast but leaves a small open area interpreted as the morphological anterior pole of the cell. The chloroplast is thin at the margin. It is split into several lobes so closely appressed that the sinuses between the lobes are scarcely discernable. As seen in optical section, each lobe is thickened inwardly and is coarsely lamellated. No distinct pyrenoid is visible, but I hesitate to say none is present because of the lamellations. Starch is present (IKI test) but scattered and unrelated to the thickened areas. There are no pseudocilia present. When stained with methylene blue, the enclosing gel is seen to contain many bacteria, oriented in radiating lines.

Although I did not observe asexual reproduction by zoospores, Flint (1974) has shown them to be unequally biflagellate. Evidence of zoospore production having taken place in my material is presumed since each of the plants was attached by a gelatinous disk a bit wider than the gel immediately above. The cells varied from hemispherical through broadly ellipsoidal to spherical. They measured 5–9  $\mu\text{m}$  in their narrowest diameter and 8–14  $\mu\text{m}$  in their largest diameter.

Christiansen (1962) discovered in a peat digging in Denmark an alga which he initially determined as *H. transversalis*. On the basis of further study of this material, he transferred the species to *Radiofilum transversale* (de Bréb.) Christiansen. Printz (1927) earlier had listed *H. transversalis* as a synonym of *Radiofilum irregulare* (Wille) Brunnthaler (1913), but did not cite this transfer in his later publication (Printz 1964). Christiansen gave a general morphological description and excellent photomicrographs of both his material and of the type herbarium material of the species *H. transversalis*.

It is evident that Flint (1974) was not aware of Christiansen's (1962) paper as she did not cite his work. Based on Christiansen's general description and the type material of *H. transversalis*, I believe the Michigan alga to be the same



FIGURES 1-6. *Parallela novae-zealandiae*. 1. Young plant with a uniseriate arrangement of cells enclosed by a continuous gel equal in thickness to the cell diameter. 2. Transition from uniseriate to biserial filament through longitudinal divisions. 3. Additional longitudinal divisions produce a tiered arrangement of four cruciately arranged cells. 4. Apex of the plant where small groups of cells are scattered irregularly throughout. 5. Whole thallus clavate in shape. 6. Pleuriseriate filament. Scale bars: 1-4, 6 = 10  $\mu$ m; 5 = 10 cm.

species. I further believe that it should not have been transferred to the genus *Radiofilum*.

First: The morphology of the chloroplast as seen in the Michigan alga is quite different from the chloroplast morphology in *Radiofilum*. It almost completely lines the cell wall where that of *Radiofilum* scarcely covers two-thirds.

Second: An obvious, distinctive pyrenoid is not discernable in the Michigan specimens. *Radiofilum* usually has one, sometimes two, clearly visible pyrenoids.

Third: The growth pattern of Christiansen’s material and of the Michigan material is clearly not that of a *Radiofilum*, but identical to *Parallela*. While *Radiofilum* is known to develop a palmelloid phase, it is an unorganized dispersion of cells in a common gel, contributed by each cell. It is never the regular, sometimes synchronous and parenchymoid (sarcinoid) development that is produced in *H. transversalis* as it grows in cellularity.

Fourth: The formation of false branches in *H. transversalis* is a dissociation phenomenon, as Christiansen described it, and not a positive growth action as in true branching or in link formation in *Radiofilum*. When *R. conjunctivum* Schmiedle does branch, it is a true branching with continued cellular contact along the main filament as well as with the branch and not a mere breaking and turning a side of a portion of the main filament as in false branching.

The distribution of *Parallela* appears to be wide spread, but this supports previous finds that the geographical distribution of freshwater algal species is much wider than that of most marine species (Round 1981). No major group of genera seems to be confined to any one geographical area as is the case with marine forms. Lists of species from many parts of the world tend to contain large number of cosmopolitan species; some “reliable lists give between 50 and 70% as cosmopolitan” (Round 1981).

Although a heterogeneous assemblage, the green algal order Tetrasporales has immobile vegetative cells that are capable of cell division, unlike those in the orders Chlorococcales and Volvocales. The colonies are never truly filamentous. Several of the Tetrasporales are so closely allied to the Volvocales (*Volvox* and related genera) that their cells have many characteristics of the volvocaceous cell. Recent RNA sequences have confirmed this phylogenetic position (Nozaki et al. 2003; Nakazawa 2004).

Until molecular data on *P. nova-zealandiae* are obtained, it is best retained within the order Tetrasporales, family Palmellopsidaceae (Table 1) as proposed by Entwisle & Skinner (2001).

One further collection from twigs in Lake Geneserath established the alga’s presence in northern Michigan. Both Stony Lake and the northern arm of Lake

TABLE 1. Systematic placement of *Parallela novae-zealandiae*.

Author	Order	Family
Flint (1974)	Tetrasporales	Palmellaceae
Santa Anna (1974)	Chlorococcales	None listed
Komárek & Fott (1983)	Chlorococcales	Palmellaceae
Entwisle (1989)	Tetrasporales	Tetrasporaceae
Entwisle & Skinner (2001)	Tetrasporales	Palmellopsidaceae



Geneserath are nutrient enriched habitats, similar to the site of the organism's original New Zealand collection.

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## ASSESSMENT OF PRAIRIE POT TRANSPLANTS AS A RESTORATION TOOL

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### ABSTRACT

We assessed two transplanting methods as possible means for increasing diversity in a restored prairie at Pierce Cedar Creek Institute in Barry County, Michigan during the spring and summer of 2006. We compared the success of seedlings transplanted as individuals with those grown in 'prairie pots'—15 cm diameter pots that contained one seedling each of four species. Each cell in which individual transplants were grown contained one quarter the amount of soil as a prairie pot. We utilized a replicated experimental design that incorporated four common prairie species, Big bluestem (*Andropogon gerardii*), Little bluestem (*Schizachyrium scoparium*), Stiff goldenrod (*Solidago rigida*) and Smooth blue aster (*Aster laevis*), as well as two less common prairie plants, Fringed brome (*Bromus ciliatus*) and Compass plant (*Silphium laciniatum*). The two uncommon species were used to assess the relative efficacy of these transplanting strategies for introducing under-represented species into prairie habitats. In general, we found that after one season of growth, seedlings raised and transplanted in prairie pots had greater survivorship and attained greater height than those transplanted individually. An exception to this trend was *A. gerardii* which exhibited greater survivorship when transplanted as individual seedlings. In addition, preparing and transplanting prairie pots required less than half the amount of time as individual transplants. Subsequent studies should track the success of transplants over multiple years to determine if this initial advantage is sustained as the plants mature. However, after one year of assessment, we conclude that prairie pots are a viable and advantageous transplant strategy for increasing species diversity in restored prairies.

**KEY WORDS:** Restoration, Prairie, Transplants, Seedlings

### INTRODUCTION

Prairie restorations are typically initiated by broadcasting or drilling a seed mix comprised of a variety of common prairie species (Sauer 1998; Montalvo 2006). Usually the resulting prairie is not as diverse as native prairie remnants because species with low germination success, as well as less competitive species, have difficulty becoming established (Brown et al. 2001; Allison 2002). Also, rare species are seldom represented in seed mixes and even if desired diversity is attained initially, species richness has been shown to decline over time in re-created prairies (Sluis 2002). Therefore restored prairies are almost always lower in plant diversity than comparable native prairies (Sluis 2002). In this study we assess a new restoration method designed to improve species diversity in seed-initiated restored prairies. Our method involves transplanting target species into restored prairies using a vector we call a "prairie pot." Prairie pots are 15 centimeter diameter pots that contain four seedlings, each of a different species (resembling a simplified miniature prairie) (Figure 1). We compared the



FIGURE 1. Prairie pots (15 cm diameter) showing four seedlings each of a different species.

performance of plants transplanted as prairie pots with individual transplants to assess the efficacy of this transplant strategy.

We focused this study on transplants because it has been our experience that transplants are an underutilized but valuable restoration strategy that can yield multiple benefits. Transplants will reach maturity more quickly than plants emerging from seed, thereby discouraging weeds and providing a source of additional seed usually within the first year (Davies et al.1999). Transplants can also include less common species, providing the restorationist a valuable tool to increase species diversity and to have a more direct influence over the final outcome of the project (Schramm, 1997; Sauer 1998).

#### METHODS

In this study we used four species typically represented in prairie restorations: two native prairie grasses: *Andropogon gerardii* Vitman (Big bluestem) and *Schizachyrium scoparium* Michaux (Little bluestem) and two native forbs, *Aster laevis* L. (Smooth blue aster) and *Solidago rigida* L. (Stiff goldenrod). We also included a less common grass, *Bromus ciliatus* L. (Fringed brome) and a rare forb, *Silphium laciniatum* L. (Compass plant) so that we could assess the use of prairie pots as a strategy for introducing under-represented species into restored prairies. The seeds for all these species were collected from natural local sites in Kent County, Michigan in late summer-fall 2005 and are all assumed

to represent local genotypes, an important consideration when establishing native habitats (Guerrant 1996). Seeds for *S. laciniatum*, a threatened species in Michigan (Herman et al 2001), were taken from garden plantings at Calvin College that had been grown from seed originally collected under a Michigan Natural Features Inventory Permit #00-1036 in 2000. All seeds were stored in Hubco Soil Sample mesh bags and received a natural overwintering stratification treatment (December 1–March 1 2006) outside the Calvin College research greenhouse in an animal enclosure.

In March 2006, seeds were sown in a soil mixture (50% Sunshine promix, 25% sand, 25% perlite) in germination flats in the Calvin College greenhouse. Seedlings were allowed to grow for several weeks until their first true leaves emerged, after which they were either planted in prairie pots or into individual cells, each of which contained 1/4 the amount of soil as a prairie pot. A potentially important difference between these two procedures is that the depth of soil was greater in the prairie pots (approximately 15 cm. than in the individual cells (approximately 9 cm.). Two groups of prairie pots were prepared, each with two grasses and two forbs. Group A included *Silphium laciniatum*, *Aster laevis*, *Schizachyrium scoparium*, and *Andropogon gerardii*. Group B consisted of *Bromus ciliatus*, *Solidago rigida*, *A. laevis*, and *S. scoparium*. Our transplanting efforts occurred during early May, 2006. All plants were kept in the greenhouse for approximately two weeks post transplanting, after which they were moved outside to an animal enclosure for hardening off.

When transplanting seedlings into prairie pots and individual cells we also performed a time trial to evaluate the amount of time required for these activities. The time involved to prepare pots and individual transplants was recorded for two different workers in the production of eight prairie pots and 32 individual transplants.

The site into which we outplanted the seedlings is a section of five year old recreated prairie located near the entrance road to Pierce Cedar Creek Institute in Barry County, Michigan (Figure 2). This section had been burned in the fall (2005), and is dominated by *Andropogon gerardii* and *Solidago canadensis* L. (Canada goldenrod). Other common species are *Panicum virgatum* L. (Switch grass), *Schizachyrium scoparium*, *Monarda fistulosa* L. (Bee balm) and *Heliopsis helianthoides* L. (Ox-eye sunflower).

At this site we marked off twelve 9 m × 9 m blocks. Within each block we located eight 1m x 1m quadrats (Figure 3). We randomly assigned four of these quadrats to receive five prairie pots, and the other four quadrats to receive 20 individual transplants (five seedlings from each of the four species). This design provided 6 large replicated areas for each group (A and B), each of which had 8 quadrats (4 with prairie pots, 4 with individual transplants). In total, 20 prairie pots as well as 80 individual transplants were introduced into each replicated site, for a total of 120 prairie pots and 480 individual transplants for each of the two groups (A and B). We assessed survivorship and measured seedling height on July 26–28, 2006. The data were analyzed with a two sample T-test (Statistix 2000).

## RESULTS

Based on previous work (Warners 2002, unpublished), corroborated by time trial comparisons in this study, prairie pots were found to be a more time efficient method for introducing transplants into a prairie. When compared to individual transplants our informal tests revealed that prairie pots require approximately 36% the amount of preparation time in the greenhouse and from earlier records, approximately 50% of the outplanting time in the field.

Figure 4 displays survivorship data collected at the end of our study period in late July. Survivorship is expressed as the overall average of the six replicated blocks in each group (A or B) (n=6, except the two species used in both groups for which n=12). The trend in this graph is greater survivorship for the prairie pot seedlings compared to individually planted seedlings. The only species that had greater survivorship when transplanted as individuals was *Andropogon gerardii* ( $p \leq 0.05$ ).

Figure 5 illustrates the mean height for each of the seedlings that survived, as

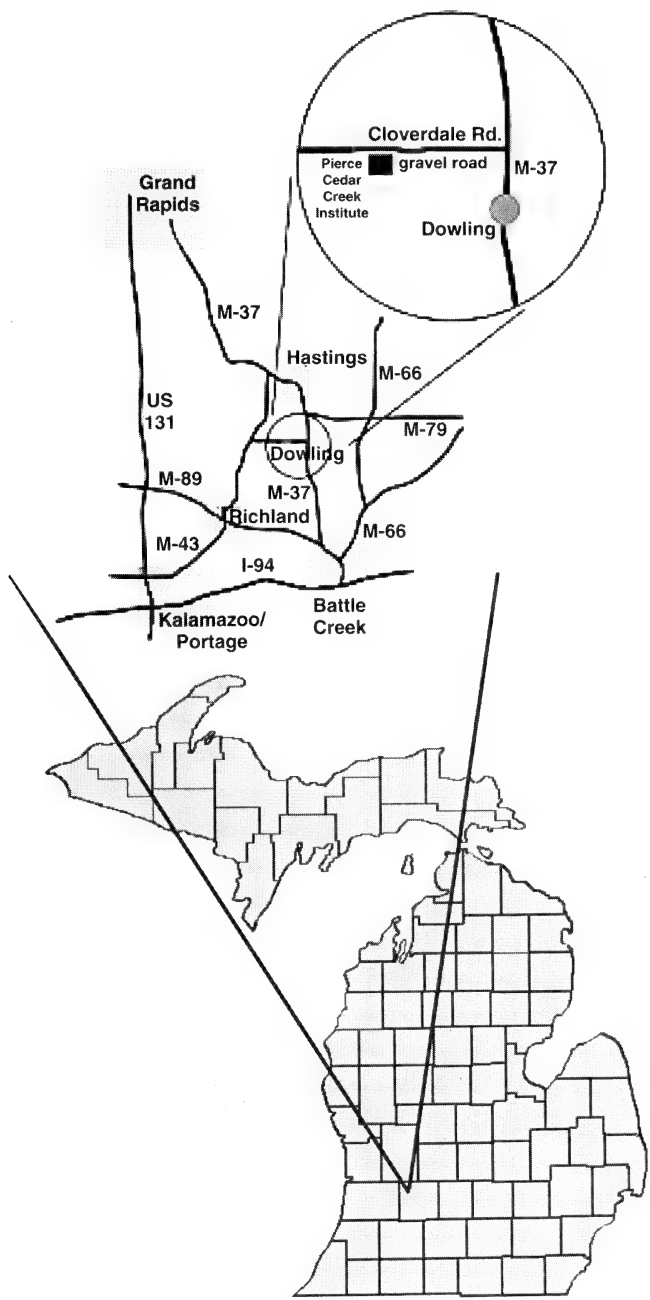


FIGURE 2. Map showing the location of Pierce Cedar Creek Institute in Barry County, Michigan. Maps taken with permission from <http://www.dnmichigan.org/contacts/county3.gif> and <http://www.cedarcreekinstitute.org/map-directions.htm>.

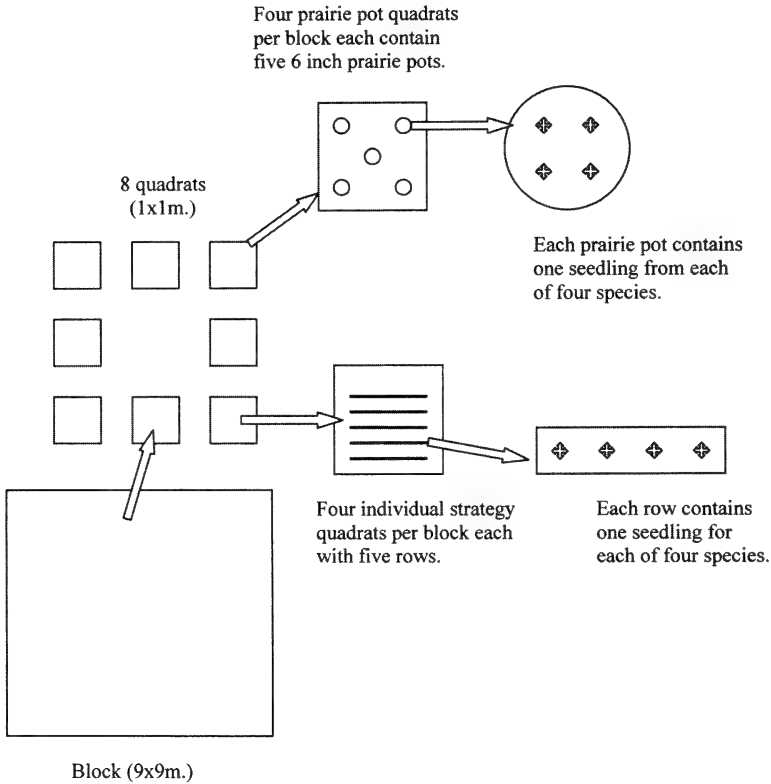


FIGURE 3. Schematic diagram of experimental design in which six replicated blocks were established for each group of species (A or B).

recorded on the final day of data collection in July. The values on the graph represent the overall average for each species in the six replicated blocks. Species height shows a similar pattern as survivorship data, with seedlings in prairie pots generally growing taller than those transplanted as individuals. However, in this comparison only two species, *Aster laevis* and *Silphium laciniatum*, showed significantly taller seedlings when transplanted in prairie pots compared to those transplanted as individuals ( $p \leq 0.05$ ).

## DISCUSSION

For introducing transplants into restored prairies, prairie pots were found to be a better strategy than transplanting seedlings individually. Prairie pots yielded better results in three ways: time required for preparing and transplanting, seedling survivorship, and seedling height. The trend in survivorship (Figure 4) illustrates an advantage for all species in prairie pots except *Andropogon gerardii*.

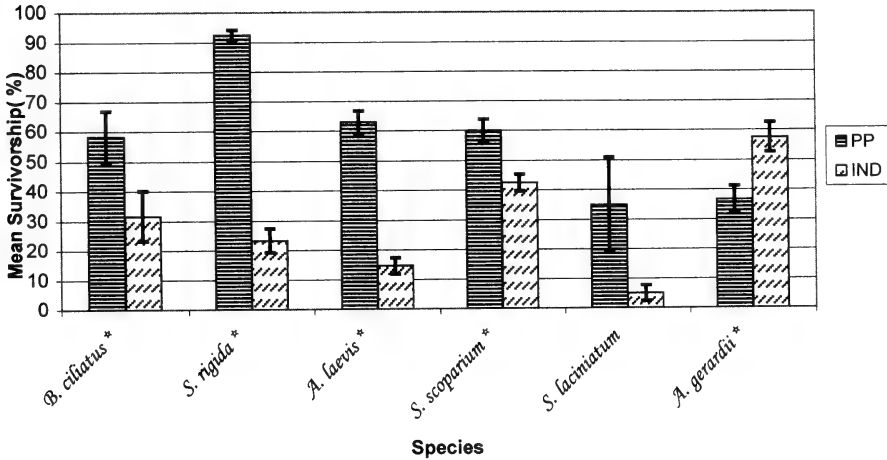


FIGURE 4. Seedling survivorship in prairie pots and as individual transplants as evaluated from the third (final) data set. Error bars represent one standard error about the mean. Asterisks indicate a significant difference using a two sample T-test ( $p < .05$ ) ( $n=6$  for all species except *S. scoparium* and *A. laevis* for which  $n=12$ ). PP=prairie pot, IND=individual seedling.

As similar experiments with prairie pots occur, particular effort should be made to identify species like *A. gerardii* that grow significantly better when planted as individuals. This knowledge will benefit those who utilize transplants in restoration projects as they work to establish key elements in their restoration efforts.

For species that do exhibit greater survivorship in prairie pots, soil volume may be an important contributor to their success. Even though each prairie pot seedling has an equivalent portion of soil available as the individual seedlings, it appears that 4 seedlings sharing  $4\times$  amount of soil conveys an advantage over 1 seedling that is allocated  $1\times$  volume of the same soil. A potential mechanism is that the greater depth provided by  $4\times$  volume of prairie pot soil (approximately 15 cm compared to approximately 9 cm in the individual cells) helps protect the seedlings from complete desiccation during dry periods (Davies et al. 1999). The possibility for mutualistic interactions among these species is also present, although none of the species in this study are capable of fixing nitrogen (Reuters 1985; Weston 2000; Maestre 2005). Subsequent studies that incorporate native legumes (for example *Desmodium* spp. and *Lepedeza* spp.) would be valuable to further understand the potential for facilitative interactions (Rice 1968; Ashton et al. 1994).

We report data that were collected only in the first year of the study, and it is possible that as these plants get larger there will be increased competition between the four seedlings planted together in prairie pots (Huddleston et al. 2004). The increased competition could lead to negative interspecific interactions in the long term, potentially offsetting the benefits we describe here. Therefore, a study such as this needs to be monitored for several seasons so that the potential long term benefit of prairie pots can be more accurately understood.

Figure 5 illustrates a trend for greater height achieved by plants in prairie

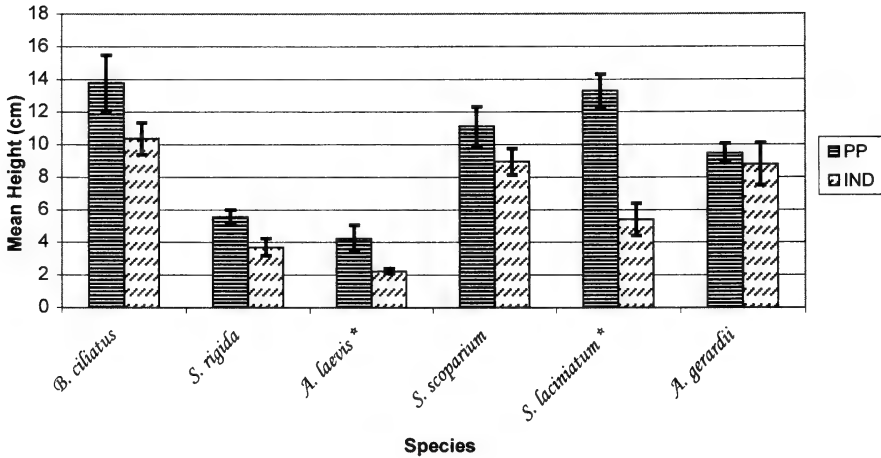


FIGURE 5. Comparison of mean height of seedlings. Error bars represent one standard error about the mean. Asterisks indicate a significant difference using a two sample T-test ( $p < .05$ ) ( $n=6$  for all species except *S. scoparium* and *A. laevis* for which  $n=12$ ). PP=prairie pot, IND=individual seedling.

pots. However, when analyzing these data, only two of the six species, *Aster laevis* and *Silphium laciniatum*, grew significantly taller in prairie pots than the individual transplants. It is important to recognize that the tallest average end height was only 14 centimeters (for *Bromus ciliatus*). This behavior of first year seedlings remaining small has been documented in wet prairies after fire and may be a common phenomenon in communities dominated by herbaceous perennials (Warners 1997). It appears that once germination success has occurred, the typical behavior of many long-lived perennials is to build up below ground reserves before investing more energy in shoot biomass. Several long-lived prairie perennials are known to require multiple years before they will flower (Dickerson et al. 1976). This observation lends further support for the need to monitor studies like this for several seasons.

Time comparisons to maximize restoration efficiency are a common component of species eradication efforts (Reuters 1985; J. McGowan-Stinski and T. J. Gostomski, unpublished). However, such consideration of time investment for restoration planting is less widely assessed. We do feel this is an important factor to consider in the overall evaluation of restoration efforts. In an informal time trial, we found that on average, prairie pots (four species in one pot) required approximately 36% less time to prepare compared with individual plant preparations (four species, each in its own individual cell). Similarly, in a previous study (Warners 2002, unpublished) the time required for outplanting prairie pots was approximately 50% of the time needed for outplanting an equal number of individual seedlings. The consistent results of these informal time trials, which occurred four years apart from each other and utilized different species, validate the time-saving aspect of the prairie pot transplanting strategy.



## ACKNOWLEDGMENTS

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## NOMENCLATURE OF *GENTIANOPSIS CRINITA* (GENTIANACEAE)

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### ABSTRACT

The name *Gentiana crinita* Froel. and its homotypic synonyms are neotypified by a specimen of the greater or wide-leaved fringed gentian of eastern North America, consistent with the long-established use of the specific epithet.

The greater or wide-leaved fringed gentian, which is native from Georgia north to Maine and Manitoba, was known historically as *Gentiana crinita* Froel. and is now called *Gentianopsis crinita* (Froel.) Ma. From a study by Fernald (1923; recently noted by Jarvis 2007), however, it has sometimes been suspected that the epithet *crinita* might correctly be applicable, instead, to Victorin's gentian, which was originally described as *Gentiana victorinii* Fernald and is now called *Gentianopsis virgata* subsp. *victorinii* (Fernald) Lammers. The latter is endemic to the intertidal flats of the St. Lawrence estuary near Québec City. With research on typification having been stimulated by the Linnaean Plant Names Typification Project, the *Flora of North America North of Mexico*, and the compilation of databases on type specimens at major herbaria, uncertainty as to the correct name of *G. crinita* should be resolved, lest the nomenclature of this well-known and much-admired species be disrupted unnecessarily.

*Gentianopsis crinita*, as *Gentiana crinita*, was the first North American species of the fringed gentians to be recognized taxonomically. Froelich (1796) distinguished this species from the European *Gentiana ciliata* L. [*Gentianopsis ciliata* (L.) Ma] by its greater plant size, basally clasping, lanceolate rather than linear leaves, larger and more numerous flowers, dimorphic calyx lobes, and corolla lobes fringed all around rather than only proximally. The description suffices to distinguish *Gentianopsis crinita* s. str. from all other North American taxa of *Gentianopsis* as well as from *G. ciliata*.

Froelich doubtless based his description of *Gentiana crinita* on specimens, because no such detailed description is present in either of the two publications he cited. In the synonymy of *G. crinita*, he listed "*Gentiana ciliata*. LINN. *syst. pl.* 1. p. 645. n. 17. var. *americana*" [fonts and punctuation as in original]. If the name *Gentiana ciliata* var. *americana* L. had previously been validly published, Froelich's citation of it as part of the basis of his *G. crinita* would necessitate consideration the identity of the plant so named by Linnaeus. Froelich also cited "*Gentiana auctumnalis* [sic] *secunda*," number 50 in Colden's (1749–1751) list of native plants in the vicinity of Newburgh, New York, a work that antedates the

1753 starting-point for botanical nomenclature. Colden's description of *Gentiana autumnalis secunda* suffices only to identify the taxon as a species of *Gentianopsis*, but no species other than *G. crinita* s. str. occurs in the area where Colden botanized.

Froelich's only reference to any publication by Linnaeus in connection with *Gentiana crinita* was in the citation quoted above. *Systema Plantarum* is a compendium of works by Linnaeus edited by Reichard (1779–1780). One of its components is Linnaeus's *Species Plantarum*, based on the second edition (Linnaeus 1761–1762) but with later additions. This is interpreted as the fourth edition of *Species Plantarum*, the third edition having been a "straightforward reprint" of the second, differing only in the insertion of errata (Stafleu and Cowan 1981, 1983). As the additions are not credited, it is not known which, if any, were written by Linnaeus while he was still active and which were written by Reichard or by others. In that work, on page 645, *Gentiana ciliata* is said to occur "in Helvetiae, Italiae, Germaniae, Austriae, Carnioliae, Canadae *montibus*" [*italics in original*]. A note on geographic variation, not present in the earlier editions of *Species Plantarum*, is added: "Haec corolla in America maxime ciliata, in Italia mediocriter; in Islandia & Norwegia tantum serrata" ("This [species] with the corolla ciliate to the highest degree in America, only moderately so in Italy, merely serrate in Iceland and Norway"). In the earlier editions no American or Canadian component of *Gentiana ciliata* sensu Linnaeus had been distinguished from the European, either morphologically or taxonomically. Notably in the present context, the phrase "maxime ciliata" is applicable to *Gentianopsis crinita* but not to *G. virgata* subsp. *victorinii*. This descriptive wording indicates that in this work, when the American component was distinguished morphologically for the first time, the distinction was based on *G. crinita* s. str.

The treatment of *Gentiana ciliata* in *Systema Plantarum* does not include the adjective *americana*, either as the epithet of a variety or otherwise, nor was any name given to the American variant. Therefore it seems likely that Froelich intended "var. americana," which he placed after rather than before the bibliographic citation, as a phrase denoting in Latin "the American variant," rather than as a name (*italics not used here in accord with this interpretation*). The similarity in format of "var. americana" to a present-day varietal name appears to be coincidental. This interpretation is supported not only by the sequence of wording but also by the absence of a Greek letter. When Froelich recognized varieties taxonomically, as he did with several European species, he designated each variety with a Greek letter, followed by a phrase name in *italics* rather than a one-word varietal epithet. Don (1837) cited "*Gentiana ciliata* β, *Americana* Lin. syst. 1 p. 645" in the synonymy of *Gentianella crinita* (Froel.) G. Don, but the addition of "β" was Don's own. Grisebach (1845) listed *Gentiana ciliata* var. *americana* L. as a name in the synonymy of *G. crinita*, and MacMillan (1892) cited it as the basionym of the combination *Gentiana americana* (L.) MacMill. Both Grisebach and MacMillan attributed the authorship to Linnaeus, with the citation abridged to "Linn. syst. 1. p. 645."

Fernald (1923) did not mention the supposed name *Gentiana ciliata* var. *americana* L. The only publication by Linnaeus cited by Fernald in this context was *Species Plantarum*, ed. 2 (Linnaeus 1761–1762). In that work, as in ed. 1

(Linnaeus 1753), Linnaeus merely gave the range of *G. ciliata* as “in Helvetiae, Italiae, Canadae *montibus*” [*italics in original*]. He neither distinguished the Canadian plants by name nor contrasted them morphologically.

Fernald concluded that Linnaeus's inclusion of Canada in the range given for *Gentiana ciliata* had been based on the taxon now called *Gentianopsis virgata* subsp. *victorinii*, of which he assumed Linnaeus had possessed a specimen, not now extant, collected by Pehr Kalm near Québec City. Linnaeus had received Kalm's collections in 1751, prior to the publication of the first edition of *Species Plantarum* (Stearn 1957). Fernald's conclusion was based on the similarity of the Québec endemic to the European *Gentiana* (now *Gentianopsis*) *ciliata*. Specimens from L'Islet, Québec (*Marie-Victorin 3183*, GH), “laid upon sheets of *G. ciliata*” were, according to Fernald, “quite indistinguishable from it until the technical details [were] examined.” He noted that the leaves of both *G. ciliata* and the Québec endemic are linear-lanceolate, whereas *G. crinita* “has the upper leaves ovate or ovate-lanceolate and broadly rounded or subcordate at base.” Linnaeus, in Fernald's opinion, “would hardly have identified it with the narrow-leaved *G. ciliata*.”

Actually, Linnaeus, as discussed below, appears to have done exactly that, as did, even more definitely, Reichard or some other author of addenda to *Species Plantarum*. The author of the addendum quoted above had observed a specimen or specimens of *Gentianopsis crinita* s. str., as indicated by his description of the distinctive corolla fringing, and nevertheless chose to retain the North American plants he thus described in *Gentiana ciliata*. With so few specimens having been available at the time, the taxonomic significance of the difference in leaf shape in this case likely remained unrecognized.

Linnaeus's (1761) inclusion of “Canada” in the range given for *Gentiana ciliata* was another point raised by Fernald. He identified “Canada” of Linnaeus's time, at least in this context, as “presumably Quebec.” As noted by Stearn (1957, p. 144), however, “‘Canada’ in the Linnaean sense does not correspond to [present-day] Canada but to a region . . . partly in Canada, mostly in the United States, where Kalm did much collecting, i.e. roughly from Philadelphia and New York northward, by way of Albany, to Montreal and Quebec, and from Albany westward along the Mohawk River to Lake Ontario and Niagara Falls.” Perhaps because of the emphasis on “Canada” in Kalm's mandate for his explorations (Jarrell 1979), Linnaeus seems sometimes uncritically to have attributed a Canadian provenance to specimens received from Kalm. For example, although he correctly stated that Kalm had collected *Gentiana quinquefolia* L. [*Gentianella quinquefolia* (L.) Small] in Pennsylvania, he said that Kalm had collected *Chironia campanulata* L. [*Sabatia campanulata* (L.) Torr.] in Canada. The latter species does not occur in Canada even as defined at that time, but could have been found by Kalm in New Jersey or along the Delaware River in easternmost Pennsylvania. Conversely, Linnaeus said that his specimen of *Potentilla pennsylvanica* L., which is not native to Pennsylvania, was from Canada, but since he had already used the name *P. canadensis*, it seems that when he had another species from “Canada” he chose an epithet that to him was essentially synonymous. *Gentianopsis crinita* is known from upland habitats in Pennsylvania and

New York, i.e. within "Canada" sensu Linnaeus, and was, as noted below, found in Pennsylvania by Kalm.

Linnaeus, toward the end of his life, is known to have discarded or given away specimens from his herbarium that he considered superfluous, so the possibility that he once possessed a specimen of the taxon *Gentianopsis virgata* subsp. *victorinii* cannot be ruled out. Kalm was in the vicinity of Québec at the right season and mentioned seeing estuarine species such as *Elymus arenarius* L. [*Leymus mollis* (Trin.) Pilg.] and *Plantago maritima* L. (Kalm 1753–1761). He did not mention gentians in that area, although he did note having found "some species of *Gentiana*" in Pennsylvania. Whether Kalm attributed any fringed gentian to "Canada" in his manuscript flora of Canada is not known, as that manuscript, which was seen by Linnaeus, was subsequently destroyed in a fire (Benson 1964, introduction to translation of Kalm 1753–1761).

The major component of Linnaeus's herbarium, now at LINN, contains only one specimen of a North American fringed gentian. (None are at S-LINN.) That specimen, LINN 328.38, represents *Gentianopsis crinita* s. str., and, according to its label, was collected by Kalm in Pennsylvania. It is likely that it was the basis for the contrast between the European and American representatives of *Gentiana ciliata* in *Systema Plantarum* by Reichard or whoever wrote that addition.

According to Fernald (1923), "in his herbarium, as shown by memoranda made at various times by Asa Gray, Linnaeus had *G[entiana] crinita* set apart as a distinct species though under an unpublished name." It is highly unlikely that any specimens from Linnaeus's herbarium were removed after Gray's time, and the set of microfiches of its contents the images now available on the Internet (<[www.linnean-online.org](http://www.linnean-online.org)>, accessioned 6 December 2007) are thorough, showing all of each sheet, yet the only specimen of *Gentianopsis crinita* therein is the one cited above. It may be that the abbreviation "pensylv." in an annotation by Linnaeus, interpreted by curators at LINN as part of "K[alm] sylvae pensylv.," designating the provenance, with "silvae" partly covered, was interpreted by Gray as a specific epithet that remained unpublished. In this interpretation, no unpublished name appears on that sheet.

Where Froelich saw specimens of *Gentianopsis crinita* and by whom they had been collected is not known. He did not travel to North America, and his own herbarium is not extant. He cited no specimens of this species, and stated only that he had seen non-European species "in variis plantarum exsiccatarum collectionibus." His attribution of *Gentiana crinita* not only to New York and Pennsylvania but also to Carolina suggests that he saw specimens collected by John Bartram, who botanized in all of those regions and sent specimens to several botanists in Europe. In North Carolina, *Gentianopsis crinita* is restricted to the mountains in the westernmost part of the state, which had been visited by few botanical explorers other than Bartram prior to 1796 (Core 1970). (André Michaux, who had explored that region, mentioned no such gentian.) Linnaeus's inclusion of "Canada" in the range given for *Gentiana ciliata* and Froelich's inclusion of Pennsylvania in the range given for *G. crinita* may have been based on the same specimen, the one cited above. In Froelich's time the main component of Linnaeus's herbarium was in England, in the care of J.E. Smith, and was

available for study by visiting botanists (Stafleu 1971), so it is possible that Froelich saw the specimen collected by Kalm.

From this study I conclude that Froelich based the name *Gentiana crinita* entirely and exclusively on the species now called *Gentianopsis crinita*. No evidence suggests that the name was based even in part on any other taxon, either through the specimens he examined or through the literature he cited.

To prevent instability either in the use of the epithet *crinita* in *Gentianopsis* or in the specific epithet applied to the species now called *Gentianopsis crinita*, a type specimen should be designated. It is not known with certainty whether the extant Kalm specimen was part of the "original material" studied by Froelich. However, if that specimen is selected as the neotype, any future uncertainty will be limited to whether it should be considered a neotype or a lectotype; there will be no question as to what specimen can legitimately be designated the nomenclatural type. Fortunately, this specimen is in good condition, and it well and clearly represents *G. crinita* s. str.

***Gentiana crinita*** Froel., *Gentiana* 112. 1796. *Gentianella crinita* (Froel.) G.Don, *Gen. Syst.* 4: 179. "1838" [1837]; *Gentianopsis crinita* (Froel.) Ma, *Acta Phytotax. Sin.* 1: 15. 1951. Neotype, designated here: Specimen collected by P. Kalm in Pennsylvania, LINN 328.38.

#### ACKNOWLEDGMENTS

I am grateful to the library staff of the Missouri Botanical Garden for access to historic publications. This paper is Contribution No. 180 from the Royal Botanical Gardens, Hamilton, Ontario, Canada.

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## NOTEWORTHY COLLECTION

## MICHIGAN

*Multiclavula vernalis* (Schw.) Petersen (*Clavulinaceae*)

*Previous knowledge.* Most lichen-forming fungi belong to the Ascomycota, but a small number are known from the Basidiomycota (Oberwinkler 2001). Among the lichen-forming basidiomycetes, *Multiclavula* is one of the most frequently encountered genera in temperate climates. Many *Multiclavula* species have a tropical distribution (Petersen 1967; Nelsen et al. 2007), but five lichenized species are known from North America (Brodo et al. 2001; Esslinger 2007). Interestingly, not all *Multiclavula* species associate with algae; some species occur free-living, while others are known to associate with moss protonemata, and possibly slime molds (Petersen 1967). The thallus of lichenized *Multiclavula* taxa is composed of small bulbils consisting of algal cells with a thick layer of fungal hyphae surrounding the algal cells (Oberwinkler 1984, 2001; Nelsen et al. 2007). The thallus covers the substrate, and basidiocarps are occasionally produced. Various morphological and anatomical characters of the basidiocarp are generally used for identification, along with the ecology of the species (Petersen 1967; Nelsen et al. 2007). Because the basidiocarps are ephemeral, *Multiclavula* species may frequently go unnoticed, and are most likely much more common than reported.

*Significance of the report.* Only one lichen-forming species of *Multiclavula*, *Multiclavula mucida* (Fr.) Petersen, is known from Michigan (Nelsen 2005). Here, a second lichen-forming *Multiclavula* species, *Multiclavula vernalis* (Schw.) Petersen, is reported for the first time from Michigan.

*M. vernalis* occurs throughout eastern North America (Bennett 2006; Brodo et al. 2001; Nelsen 2006) and globally, is one of the most widespread of all *Multiclavula* species (Petersen 1967; Petersen & Kantvilas 1986), but has not been reported from Michigan (Fryday et al. 2001).

*Diagnostic characters.* *Multiclavula vernalis* typically occurs on soil; the fungal hyphae associate with algae (*Coccomyxa*), forming a lichenized crust over the substrate. It produces simple to lobed, clavate (club-shaped) basidiocarps that are cream to orange in color (Fig. 1) and may be up to 2 cm tall (Petersen 1967).

*Specimen citations.* MICHIGAN. Houghton County: Found on soil in the Michigan Tech Trails, on the north side of the southern trail in Peepsock Loop, near where Peepsock Loop meets the Linden Loop. 13 May 2007, Nelsen 3979 (MSC).

*Multiclavula mucida* (Fr.) Petersen (*Clavulinaceae*)

*Previous knowledge.* *Multiclavula mucida* is the most cosmopolitan of the *Multiclavula* species (Petersen 1967). In North America, it is known from south-





FIGURE 1. The terricolous *M. vernalis*, growing amongst mosses. A layer of algae and fungal hyphae cover the soil, and cream to orange basidiocarps (shown in image) are produced.

ern Ontario (Wong & Brodo 1992), Wisconsin (Wetmore & Bennett 2002; Thomson 2003; Lay 2004) and throughout eastern North America (Brodo et al. 2001). It forms a lichenized crust (with *Coccomyxa* algae) over shaded, rotten logs and has cream to tan basidiocarps which are clavate and simple or sometimes basally branched (Petersen 1967; Brodo et al. 2001). Basidiocarps of *M. mucida* are similar in size to those of *M. vernalis*, growing up to 2 cm high (Petersen 1967).

*Diagnostic characters.* Macroscopically, *M. vernalis* and *M. mucida* differ especially in their ecology and basidiocarp color. Microscopically, the two differ in a number of characters. The basidia of *M. vernalis* are shorter than those of *M. mucida* (7–20  $\mu\text{m}$  in *M. vernalis* and 15–25  $\mu\text{m}$  in *M. mucida*), while the sterigmata are shorter in *M. mucida* (up to 4  $\mu\text{m}$  in *M. mucida* and up to 7  $\mu\text{m}$  in *M. vernalis*) and sometimes supernumerary (more than four) in *M. mucida* (Petersen 1967). Additionally, spores are larger in *M. vernalis* ( $4.5\text{--}7.7 \times 1.8\text{--}3.2$   $\mu\text{m}$  in *M. mucida* and  $8\text{--}12 \times 2.5\text{--}3.5$   $\mu\text{m}$  in *M. vernalis*), while the cells of the contextual hyphae are much shorter in *M. vernalis* (Petersen 1967).

*Significance of the report.* The *M. mucida* collection reported appears to be the second from the Upper Peninsula of Michigan, with the first being made in Baraga county (Nelsen 2005). *M. mucida* is also known from Michigan's Lower Peninsula (A. Fryday, personal communication), and the record presented here is

the northernmost record in Michigan. Its rarity is probably related to the ephemeral nature of *M. mucida*, which makes collecting difficult.

*Specimen citations.* MICHIGAN. Houghton County: Churning Rapids, 30 September 2006, *Nelsen 3978* (MSC). Found on rotting log near stream just off of Great Oaks Trail, approximately 300m from trailhead at Christensen Road.

#### ACKNOWLEDGEMENTS

Carrie Andrew is thanked for discovering the *M. vernalis* and for discussion. Carrie Andrew and Mark Leach are thanked for companionship and assistance in the field. Jim Bennett, Alan Fryday and Cliff Wetmore are thanked for discussion, and Alan Fryday for improving the manuscript.

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## NOTEWORTHY COLLECTION

## WISCONSIN

*Ranunculus cymbalaria* Pursh (Ranunculaceae). Alkali buttercup, seaside crow-foot.

*Previous knowledge.* Seaside crowfoot is distributed heterogeneously throughout much of North America, but it is conspicuously absent in southeastern U.S. (USDA 2007). The halophile-like species flourishes on mud and gravel, particularly under brackish or alkaline conditions and limited competition. The floristic rating as a wetlands indicator for *R. cymbalaria* is OBL (Obligate Wetland).

In Wisconsin, *R. cymbalaria* is one of the more diminutive and rare buttercups. The creeping perennial forb is a state threatened species, known from just seven counties out of 72. With one inland exception, Walworth County, *R. cymbalaria* has been collected from six counties bordering the Great Lakes (Lake Michigan: Marinette, Brown, Sheboygan, Racine and Kenosha; Lake Superior: Douglas (Wisflora 2007).

Historically, the species occurred in Walworth, Racine, Kenosha, Sheboygan and Manitowoc counties (Brynildson 1982) and was characterized as "Very rare along Lake Michigan shore in Manitowoc, Racine and Kenosha counties, inland only at Lake Geneva in Walworth County where collected in 1885" (Fassett 1947). While *R. cymbalaria* grows locally in disturbed habitats today, it has been suggested that human-caused alterations of lakeshore habitats was responsible for elimination of any known original/relict populations in Wisconsin (Brynildson 1982).

Since the early 1980s, the number of documented Wisconsin records for *R. cymbalaria* has quadrupled. The plant is locally abundant in bare muddy places, on wet clays, gravels, or gravel-sand or gravel-cinder mixtures, growing in ditches and railroad rights-of-way, as well as in street-side bluegrass lawns and mowed grassy highway strips, notably in the City of Superior (Douglas County) (Pers. Comm., Theodore S. Cochrane, 4 October 2007). The habitats often ascribed to it—wet meadows, boggy shores, stream banks, and seepage areas—apply to only a fraction of the WIS collections (and several of these lack habitat information altogether) (Pers. Comm., Theodore S. Cochrane, 31 October 2007). Thus, *R. cymbalaria* is probably a native pioneer species, colonizing open disturbed wet substrates where competition for space and resources is sparse. This would explain its occurrence in artificial as well as more natural habitats, such as fluctuating Great Lakes shorelines. On a 0–10 scale, the coefficient of conservatism (C) for *R. cymbalaria* equals two (Wisflora 2007), further reinforcing the assessment that *R. cymbalaria* is likely a pioneer species.

*Significance of the report.* On 28 June 2007, Thomas Underwood, Oshkosh, WI, discovered a small flowering population of *R. cymbalaria* on a (periodically wet) packed crushed dolomite gravel parking area at the end of Puchyan Marsh Road, Green Lake County, WI (SW 1/4 NW 1/4 Section 1, R12E, T16N;

N43°53.452 W089°01.626). Identification was verified and a voucher specimen collected as a county record by T. L. Eddy on 29 June 2007 (Eddy 5213, OSH). It is unknown if the Green Lake County population is part of the original (pre-European) local flora (Eddy 1996), but it is presumed that the plant was introduced via human-caused disturbances, e.g. road fill, vehicle and pedestrian traffic, or perhaps even by migrating waterfowl.

A search of the roadbed and right-of-way vegetation did not reveal any other colonies of *R. cymbalaria* growing nearby. Associates of *R. cymbalaria* growing at the Green Lake County site include *Agrostis gigantea*, *Ambrosia artemisiifolia*, *Centaureum pulchellum*, *Eleocharis acicularis*, *Hordeum jubatum* and *Juncus nodosus*.

*Diagnostic characters.* In Wisconsin *R. cymbalaria* flowers from June through July (Wisflora 2007), while Gleason and Cronquist (1991) report flowering from May to October. Stems are dimorphic: flowering stems (5–15 cm) and prostrate stolons that readily propagate clones via rooting nodes. The (1–10) yellow flowers are subtended by mainly basal leaf blades with cordate base and crenate margins above. The yellow petals are slightly longer ( $2\text{--}7 \times 1\text{--}3$  mm) than the five glabrous, spreading sepals ( $2.5\text{--}6 \times 1.5\text{--}3$  mm) (Whittemore 1997). The glabrous fruits are arranged on a cylindrical head up to 12 mm. Achenes are  $1\text{--}1.4(2.2) \times 0.8\text{--}1.2$  mm long, longitudinally nerved with a persistent straight conic beak (0.1–0.2 mm). The most similar taxon to *R. cymbalaria* in Wisconsin is *R. flammula*, although the leaf shape immediately distinguishes them (Gleason and Cronquist 1991).

*Specimen citations.* One voucher (GREEN LAKE CO.: Eddy 5213, OSH; accession number OSH-115423) was collected and examined for this report. A list of other Wisconsin herbarium records with specimen citations is available online via Wisflora (<http://www.botany.wisc.edu/wisflora/>).

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## INSTRUCTIONS TO AUTHORS

1. Create text in 12-point Times New Roman font and double space paragraphs throughout. Papers should be organized as follows: Title, Author(s) and address(es), Abstract with up to 5 keywords, Introduction, Materials and Methods, Results, Discussion, Acknowledgements, Literature Cited, Tables, Figure Legends, and Figures. Sections may be omitted if not relevant. All pages should be numbered. Please contact the editor regarding any questions related to formatting.
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On the cover: Wisconsin threatened *Ranunculus cymbalaria* (Ranunculaceae),  
alkali buttercup or seaside crowfoot; local population discovered growing on  
dolomitic gravel of Puchyan Marsh Road, Green Lake County, WI.  
Photograph by T. L. Eddy, 29 June 2007 (see Noteworthy Collection, p. 127).